A Housing Energy Management Program Report

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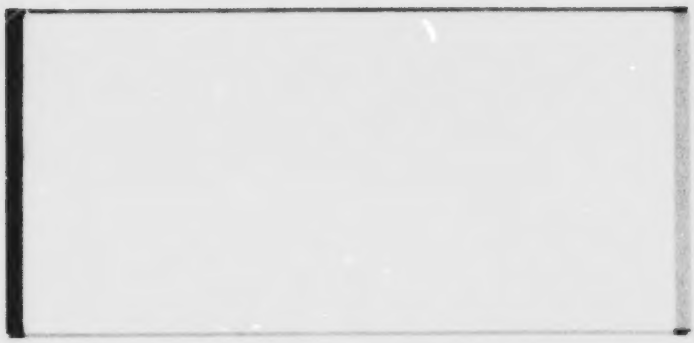

PRIMROSE HOUSING CO-OPERATIVE

MOISTURE DAMAGE STUDY

Undertaken jointly by the Ontario Ministries of Municipal Affairs and Housing and Energy under the Housing Energy Management Program (H.E.M.P.)

Prepared for

Ontario Ministry of Municipal Affairs and Housing, Technical Services Division Research & Development Section

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CONTENTS

		Page
ACKNOWLEDGEMENTS		
CONTENTS		
INDEX TO FIGURES		
INDEX TO PHOTOGRAPHS		
SECTION 1.0	EXECUTIVE SUMMARY	1
SECTION 2.0	INTRODUCTION	6
2.1	General	6
2.2	Building Description	7
2.3	Problem Description	9
2.4	Objectives	10
SECTION 3.0	TESTING	11
3.1	Surface Temperature Measurement (Thermal Bridges)	12
	.1 Method	12
	.2 Results	13
3.2	Hygrothermograph Testing (Moisture Levels)	36
	.1 Method	36
	.2 Results	36
3.3	Tracer Gas Testing (Infiltration & Stack Effect)	37
	.1 Method	38
	.2 Results	39
3.4	Field Observations	45
	.1 Building Deficiencies	45
	.2 Miscellaneous Observations	51

CONTENTS (cont'd)

		Page
SECTION 4.0	CORRECTIVE TRIAL MEASURES	57
4.1	General	57
4.2	Selection of Measures	58
4.3	Exterior Closets	63
	.1 General	63
	.2 Slab Temperatures (Closets)	75
	.3 Flashing	78
4.4	Slab Heating	81
4.5	Air Sealing & Ventilation	86
	.1 Description	86
	.2 Air Sealing	86
	.3 Ventilation	88
	.4 Ventilation Analysis	91
	.5 Ventilation Control	93
	.6 Moisture Levels	94
SECTION 5.0	CONCLUSIONS	96
5.1	Workmanship	96
	.1 Water Leakage	96
	.2 Fire Stopping	97
	.3 Lack of Air Sealing	97
5.2	Design	98
	.1 Thermal Bridges	98
	.2 Door Frames	102
	.3 Window Frames	103
5.3	Lifestyle	103
5.4	Technology	105
	.1 Tightness/Air Leakage	105
	.2 Stack Effect	106
	.3 Ventilation	107
	.4 High Insulation Levels	107

REFERENCES

LIST OF APPENDICES

INDEX TO FIGURES

Figure		Page
3.1	SF_6 Concentration with Time, Upper Unit, Block 2	42
3.2	SF_6 Testing Result, Townhouses	43
3.3	SF_6 Testing Results, Apartment	44
4.1	Calculated Surface Temperatures, Interior and Exterior Surfaces at Design Condition	76
4.2	Comparison of Humidity Data 1982 vs. 1983 Vertically Related Upper and Lower Units	88
4.3	Humidity Ratios During Trial of Block 2 Upper Unit Ventilation Fans	89
4.4	One Week Average of Difference Between Indoor Humidity Ratio and Outside Humidity Ratio	90
4.5	Chart of Predicted Thermal Bridge Conditions at "Design" Conditions	95
5.1	Living Room & Bedroom Floor Temperature Profile in 1515, #3	100

INDEX TO TABLES

Table		Page
4.1	Summary of Closet Floor Temperatures	75

INDEX TO PHOTOGRAPHS

Photo		Page
3.1	Brick at Surface of Common Balcony 4th Level Block 1	46
3.2	Common Balcony 4th Level Block 1	49
3.3	Dust-Marking over Exterior Wall Studs	53
3.4	Window-Sill, Typical Aluminum Slider	54
3.5	Window-Sill, Fixed in Aluminum Frame	55
3.6	Steel Window and Door Frame	56
4.1	Interior View, Exterior Closet	64
4.2	Exterior View, Exterior Closet	65
4.3	Existing Floor Insulation, Exterior Closet	66
4.4	Exterior View, Closet after Re-insulation	73
4.5	Interior View, Closet Removed	74
4.6	Exterior View, Closet Prior to Flashing	79
4.7	Exterior View, Closet with New Flashing	80
4.8	Location Type II-c, Interior View - Frost on Floor	82
4.9	Interior View of Slab-Heater Installation	84
4.10	Exterior View, New Soffit over Slab Heater	85
4.11	Exiting Basement Ventilation Fan with New Switch for Independent Operation	87
5.1	Exterior, Block 2 Slab Overhang	101

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SECTION 1.0 EXECUTIVE SUMMARY

Primrose Housing Co-operative is a recently constructed (1978) group of buildings in which severe internal moisture problems were experienced commencing after occupancy.

Problems were experienced in blocks 1 and 2, being of different construction than the remainder of the project. Blocks 1 and 2 are cast-in place concrete structures, using steel-stud, non-load bearing exterior walls, insulated with fiberglass and faced with brick veneer. They are four stories in height, the lower stories comprising townhouses, the upper stories forming apartments (commonly called "stacked townhouse"). Ventilation by individual, manually controlled exhaust fans located only in rooms without windows, that is kitchens, some baths and basement areas. No ventilation is provided in the apartment corridors.

The concrete structure is exposed at many points: at slab edges, where projected to form balconies, at the ends of the blocks (where it is insulated on the interior), and at changes in building profile where dividing walls are projected to form buttresses and architectural elements.

Problem Description

Most problems appeared in upper units while some lower also units experienced problems. These problems included the following:

- moisture damage to drywall around windows
- water damage to floors at edges
- recurring mould growth at ceiling edges
- paint peeling and rusting of exterior door frames
- water damage and mould growth in closets located on exterior wails
- marking over exterior wall studs
- warping and delamination of exterior doors

A preliminary study showed interior humidity levels of 40-60% R.H. in lower units and 40 to 80% R.H. in upper units.

Problem Analysis

After the initial testing period several mechanisms were identified as contributing to the problems being experienced.

1) Airtightness Due to the nature of the construction system used, natural ventilation rates were appreciably lower than would be expected in a detached, frame building of equivalent area. The construction quality was fairly poor and the air-vapour barrier sealing measures called for by the designers were not implemented.

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2) Stack Effect As the natural ventilation pattern in buildings is vertical during the winter, that is, infiltration occurs in the lower part of the building and exfiltration occurs in the upper part of the building, the upper units experienced only exfiltration. The incoming air for the upper units come from the townhouses below. The effect of this mechanism was to amplify severely the already high moisture levels occurring in the building.

The air which "ventilated" the upper units was essentially "second hand" and reached very high moisture levels when additional moisture from the upper units was added. This dominant effect was due to poor sealing at floor levels around piping and electrical penetrations.

3) Thermal Bridges Thermal bridges occur when the concrete structural elements (floor slabs and shear walls) penetrate the insulated envelope of the building. Cold spots occur on the surface of these thermal bridges due to the high thermal conductivity of the concrete structural material and the thermally unbroken attached brick veneer. Depending on the construction detail and interior conditions these cold spots condense water and can cause ice formation if severe enough.

As theoretical analysis of such bridges is difficult extensive field measurements were made to evaluate the severity of bridge types.

"Design" temperatures of 20°C indoor, -20°C outdoor were used to predict surface temperatures of thermal bridges from measurements. The maximum acceptable humidity level under these conditions is 40% relative humidity indoor which corresponds to the onset of condensation on the interior surface of a double glazed window (i.e. dewpoint of 7°C). A number of thermal bridge types yielded predicted surface temperatures lower than 7°C, several even temperatures lower than the freezing point. This is illustrated in the table below and indicates that under "normal" building humidity and typical winter temperatures, surface condensation can occur for significant periods of time and thermal bridge types will exhibit frost within the living space. Good building design should ensure that no interior surface is colder than the double glazing.

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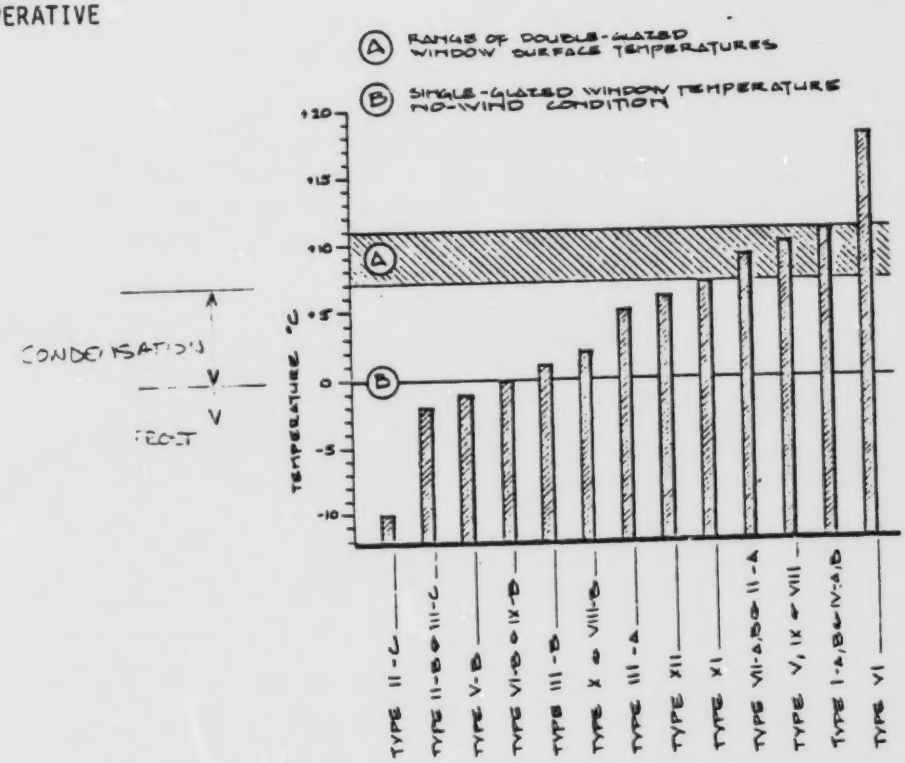

Interior surface temperatures of types of thermal bridges identified at conditions of 20°C indoor, -20°C soutdoors. Onset of condensation corresponds to 40% R.H. indoors.

4) Exterior Water Leaks Poor detailing occurred with respect to shedding of precipitation, especially at balconies and could potentially be responsible for some water entering at floor or ceiling junctions. Some slopes of balconies were found to be level or towards the building wall. As well, insufficient overhangs of concrete slabs acting as roofs caused extensive wetting of exterior brickwork. It would be relatively easy for water to make its way into the building. However, under test conditions no water was observed to enter the living space via this route and moisture patterns observed previously corresponded closely to occurrence of condensation.

5) General The cause mechanisms can be stated as follows:

Low rates of natural ventilation, the absence of mechanical ventilation as humidity control of a continuous nature, and an air flow pattern from lower units to upper units result in excessively high internal humidity levels, particularly in upper units. Condensation and damage occurs at windows and at thermal bridge locations. Further analysis shows that even if humidity levels were reduced to below levels accepted as normal in the industry, certain thermal bridge locations can continue to produce condensation and subsequent damage.

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Corrective Trial Measures and Results

1) Humidity Levels In order to reduce humidity levels in the upper units, an attempt was made to seal the air routes from lower to upper units and the amount of ventilation varied by operating existing exhaust fans in a variety of modes: continuously on, at reduced speed and "normal use" (i.e. off).

   Results did not produce a demonstrable, long term reduction in humidity levels due to occupant interaction with the manual fan controls (they are not used) and to a probable lack of complete sealing between floors. Short-term ventilation tested showed that marginally acceptable ventilation and humidity reduction might be achieved by continuous operation of the existing exhaust fans, but that this would not ensure humidity reduction at all times.

2) Thermal Bridges Two approaches were taken to rectify problematic thermal bridges. The first used heating elements to warm cold elements, the second employed insulation applied to the exterior of the bridge location.

   Exterior insulation was not successful and did not produce significant warming. This was attributed to the fact that the brick veneer represents a significant "thermal bypass" of the insulation and is not capable of being isolated without significant expenditure.

   Heating elements were found to be successful, resulting in significant warming of the interior surfaces without large energy consumption.

Conclusions

The moisture problems identified in this study could have been avoided at the design stage if better understanding existed regarding the housing type (including occupant lifestyle) and the behaviour of the building envelope. The current O.B.C. requirement for ventilation (Section 9.33) is inadequate with respect to setting minimum ventilation requirements independent of occupant control. The ventilation system should be capable to control humidity to maximum of 40% in winter whether by intermittent exhaust fans on dehumidistat or continuous ventilation, possibly with heat recovery. Considering that these buildings are relatively airtight, positive supply of fresh air is required for exhaust systems to be effective.

The problematic thermal bridges (i.e. surfaces that cause condensation at normal humidity conditions) demonstrate a lack of understanding by designers as to evolving building envelope technology. In the last few years, building skin design has been moving towards higher insulated and more airtight construction. Inadequate understanding of highly conductive elements within this context and high humidity due to inadequate ventilation strategies combine to cause severe moisture problems.

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Construction quality in this project regarding airtightness was poor. However, had the building been executed according to the intent of the specifications, it would likely have experienced equally severe problems of condensation.

Lifestyle of individual occupants did produce a variation in levels of damage, but the universality of the problems experienced indicate that lifestyle was not the determinant factor. Ventilation trials did reveal, however, that occupants should not be relied upon to control ventilation systems in order to provide humidity control.

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SECTION 2.0 INTRODUCTION

2.1 General

In January of 1981, ALLEN-DRERUP-WHITE LTD. was contacted by Primrose Housing Co-Operative Inc. (PHCI) to determine the causes, and recommend remedies for the severe internal moisture problems being experienced in Blocks 1 and 2 of the recently constructed (1978) housing project.

Following review of reports by other consultants and site inspections Allen-Drerup-White Ltd. recommended a more detailed testing and evaluation procedure be carried out in order to determine the mechanisms involved so that appropriate remedial work could be recommended.

Discussions between PHCI management, CMHC, the Ministry of Municipal Affairs and Housing and Enerplan Consultants Ltd. led to an agreement between PHCI, the Ministry and Enerplan Consultants to carry out a study of the building, to implement, test and evaluate trial remedial measures and to report on the findings. The need for such a study arose out of awareness that several other buildings, built during the same period, were experiencing similar problems which were resulting in costly property damage and for which no apparent solutions were known.

The Ministry of Municipal Affairs and Housing provided funding for study, testing, specification of trial remedial measures, evaluation and report preparation, while PHCI provided capital funds for remedial work from their budget of $25,000 remaining from construction costs. Work included identifying thermal bridges with condensation potential, testing for sealing possible stack driven airflow paths between upper and lower units, and implementing improved ventilation strategies to reduce humidity levels. Co-operative members assisted the study teams by changing recording charts and recording observations of water leakage. Project co-ordination was undertaken by Enerplan Consultants with Allen-Drerup-White Ltd. as major subcontractor for technical investigation, specification and reporting. MacLaren Engineering Ltd., was subcontracted for tracer gas testing work.

Work began in January of 1981 and was completed in March 1984.

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2.2 Building Description

Type

While Primrose Co-operative is made up of several buildings of differing construction types, the two structures (blocks 1 and 2) of concern to this study are the same construction type. Both buildings are four storeys in height, with block one being divided into two-storey (two bedroom) apartments on the upper levels. Block 2 is divided into three-storey townhouses on the lower levels and single storey apartments on the upper level. In both blocks apartments are accessed via an interior corridor served by enclosed stairwells.

Arrangement

Both blocks are laid out on a primarily north-south axis with block one having most windows facing west, and block two having most windows facing east. Block 2 does however contain four townhouses and two apartments having west-facing windows.

Structure

The buildings' structure consists of cast-in-place concrete shearwalls and continuous flat plate slabs. Shearwalls occur between units and interior partitions within units are steel stud with drywall covering. Non-structural fire-separations (between apartments and corridor) are concrete block with drywall cover.

Skin

Exterior building skin consists primarily of a 'rain screen' system composed of:

- 100 mm face brick
- 25 mm air space
- building paper
- 12 mm exterior gypsum board
- 38 x 89 steel stud frame with RSI 2.1 fibreglass batt insulation
- polyethylene vapour barrier
- drywall

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2.2 Building Description(cont'd)

The brick rests directly on the slab edge and is restrained laterally by metal ties to the steel stud framework. The concrete structure is exposed at all slab edges, and forms the building exterior skin in combination with 1-1/2" of rigid insulation at end walls and at checks in the building elevation. Several slab overhangs are present, ranging from .6m to 1.2m and are insulated on the underside with 1-1/2" of rigid insulation. A sprandrel beam is formed in the slab edge at the overhangs which is not insulated. At balconies the slab sometimes projects completely beyond the building face or forms the roof of building area below for part of its projection. In the latter case, 1-1/2" rigid insulation is placed on the interior. In some instances, the structural slab is projected to form the ceiling of a building area below and is insulated on the exterior with 1-1/2" rigid insulation. The structure also extends beyond the building envelope where shearwalls are projected beyond the building face in order to support an overhang above, notably in block two.

Basements are concrete and insulated to their full height on the interior.

The roof is flat, inverted membrane type with 3" of rigid insulation.

Windows are aluminum frame with fixed upper sections and horizontal sliding lower sections. Fixed glazing is double sealed unit type, movable glazing is single thickness with double sashes to provide double glazing. Balcony and fire exit doors (block 1) are solid core wood, with steel frames. Sidelites to the balcony doors are double sealed unit glass also set in steel frames. Some openings (notably in end walls) are filled with a combination fixed double sealed unit lite and insulated, aluminum covered panel both set in an aluminum frame.

Heating

Heating is provided by electric baseboard with individual room line voltage controls.

Ventilation

Ventilation is provided by ceiling mounted exhaust fans located in kitchens and bathrooms exhausting directly outside, which are controlled by wall-mounted on-off switches. One bedroom apartments (block 2) are equipped with cabinet type exhausters which serve both bathroom and kitchen and are controlled by 3-way switches. Townhouse basements (which do not have windows) are equipped with ceiling mounted exhausters connected to operate simultaneously with the lights.

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2.3 Problem Description

Most upper units in Blocks 1 & 2 experienced extensive deterioration of interior finishes due to moisture during the winter months. Many lower units also experienced similar deterioration.

Visible problems included:

- serious deterioration of drywall surrounds at windows and doors due to moisture
- accumulated water at exterior floor areas, resulting in staining and lifting of the wood tiling
- extensive mould growth at ceilings at exterior walls (continous 18" band) which would begin to reappear immediately after painting
- paint peeling and rusting of painted steel door frames
- continuous water accumulation and heavy mould growth in exterior closets. Reports were received but not confirmed of clothing being frozen to the wall
- accumulation of frost and ice on floors
- extensive "dust marking" and mould growth over stud locations on exterior walls
- warping and delamination of exterior doors

A preliminary survey of humidity levels revealed ranges of 40 to 60% (5.8 to 8.8 g moisture/kg dry air) in lower units and 40 to 80% (5.8 to 11.8 g/kg) in upper units. The outdoor moisture levels were about 2.5 g/kg.

From the initial investigation several factors were identified as being involved in the problems being experienced:

- construction (workmanship)
- technology (materials and practice)
- building design
- occupant lifestyle

More specifically the factors involved were considered to be:

- high levels of airtightness
- stack effect
- thermal bridges
- air leakage
- high levels of insulation
- insufficient ventilation
- high occupant moisture load

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2.4 Objectives

Based on the information gathered at the start of the study and preliminary analysis of the problems the following objectives were formulated by the involved parties:

.1 To clearly identify the problems associated with the building design, technology and lifestyle which has resulted in these unacceptable conditions.

.2 To propose a number of design solutions to overcome the condensation problem based on site investigation and cost consideration.

.3 To establish monitoring options for the proposed design solutions. At minimum the monitoring is to include humidity and visual inspections.

.4 To implement a number of the proposed design solutions.

.5 To monitor the project over a full heating season and thus assess success of the corrective work taken.

.6 To report on remedial options, construction and results of monitoring.

.7 To allow provision of project information and report results to the public and private sectors.

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SECTION 3.0 TESTING

The testing program for this project was designed with two principal objectives in mind:

1) To construct, based on field measurements, an emperical model of sufficient accuracy to allow prediction of the surface conditions of thermal bridge sites, at the design temperatures and humidities. This information is fundamental to any capacity to make decisions concerning the capital cost implications of competitve remedial strategies.

2) To obtain a reasonable model of the air movement 'system' within the buildings. Such an understanding is fundamental to the design of an effective, least-cost ventilation system, and is also critical to designer's ability to select the most viable solution by considering the variables of capital and operating costs.

It was also of interest to perform a general survey of the moisture levels occurring in the project for correlation with occupant questionnaires and field observations so that the effect of occupant lifestyle on the observed problem could be evaluated.

It is for these reasons that the testing relied heavily on medium term temperature and humidity recording (hydrothermograph) of unit interior ambient conditions. This testing was supplemented by the use of tracer gas testing which was required to obtain an accurate baseline of infiltration values.

All emperical data was supplemented by extensive field notes, and the use of depressurization fans, and smoke pencils to determine leakage sites and air-flow paths.

In some cases, investigation into specific problem areas was performed by physically opening building assemblies.

Field investigators were qualified technologists and engineers with thorough training in building science.

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3.1 Surface Temperature Measurement

Direct measurement of surface temperatures was desirable in order to characterize and identify problematic thermal bridges. Direct reading of actual surface temperatures is preferred[3] over analytical predictions which are subject to large errors. Thermography would be useful in some cases for thermal bridge location but does not yield accurate surface temperature data, without which characterization of individual thermal bridges would not be possible.

3.1.1 Testing Method

Bridge conditions were divided into 12 major sections according to general location. Some of these sections have sub-sections depending on the individual case. The surface temperature of examples in each case were measured using a thermister probe with digital readout resolving to 0.1°C. Indoor and outdoor air temperatures were also measured.

Assuming a linear relationship exists between these temperatures,[3] the surface temperatures at the design condition (i.e. 20°C 40% RH indoors, -20°C outdoors) were predicted. The method of predicting the surface temperature at the design conditions as well as the outdoor temperature at which condensation will start to occur are shown in Appendices 4 and 5. The dew point for the above given indoor conditions is 7°C. The anticipated period of condensation was predicted based on the hourly data summary published by Climatological Service Division for Toronto.[2]

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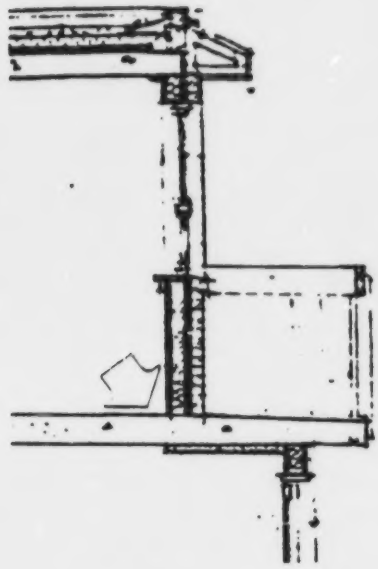
3.1.2

THERMAL BRIDGE TEST RESULTS



TYPE I: Extended Floors

(a) Floors extended to fire escape corridor

e.g. All bedroom floors in 2 bedroom apartment.

EXAMPLE MEASURED: 1509 #5

TEMPERATURE MEASURED:

Indoors 21°C Outdoors: -1°C Surface: 15°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 11°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) Marginal Problem. Condensation should not occur at slab-wall interface under normal humidity conditions.

(2) 7 of 11 units reported having water on floor. In 5 of 11 of these units it is believed water came from outside. The remaining 2 units have water on floor directly under window.

(3) Removing snow from corridor cured the leakage problem, probably a flashing problem.

(4) The inner-most glazing surface of the window exhibited condensation which ran down and wetted the first foot below the sill. Water also collected in small puddles on the floor directly under the corners of the window. This evidence suggests that humidities significantly higher than 40% were maintained in these two units.

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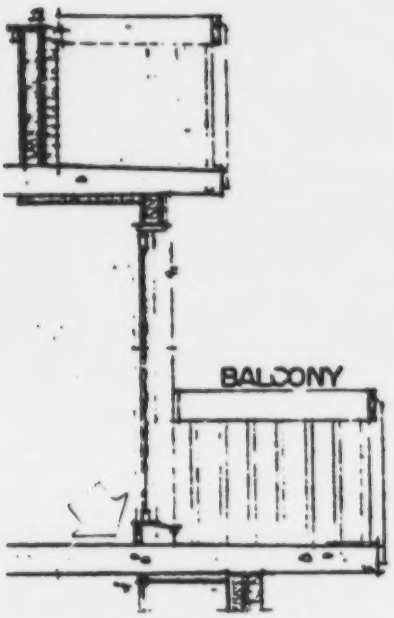
3.1.2 (cont'd)
THERMAL BRIDGE TEST RESULTS

TYPE I: Extended Floor

(b) Floor extended to balcony

e.g. All living room floors in 2 bedroom townhouses and some living room floors in 1 bedroom apartment.



EXAMPLE MEASURED: 1505 #1

TEMPERATURE MEASURED:

Indoors 17°C Outdoors: -6°C Surface: 12°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 11°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) Marginal Problem. Condensation should not form on slab in the form of water stain on carpet.

(2) 1 of 11 units reported damage on this type of floor.

(3) Water condenses on balcony window and door frame drips down onto the floor. In this one unit the humidity was not high enough for a small puddle to form. In other cases only beads form on the frame without causing actual nuisance or damage.

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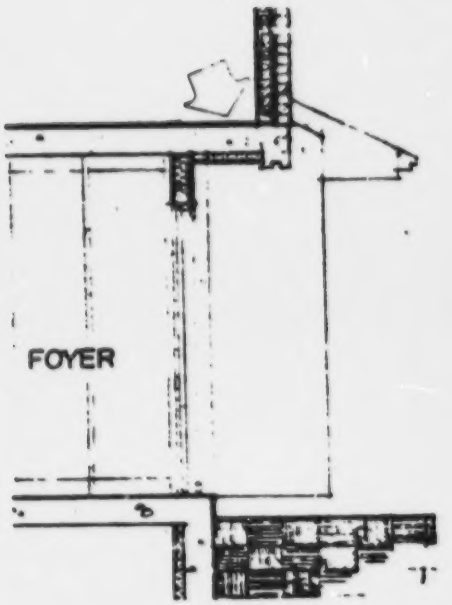
3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE II: Overhang

(a) Townhouse overhang, centre unit without carpet

e.g. All floors above entrance door in block 2 townhouses



EXAMPLE MEASURED: 1529 #9

TEMPERATURE MEASURED:

Indoors 21°C Outdoors: -8°C Surface: 13°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 9°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) Marginal Problem. Condensation should not form on slab.

(2) 1 of 12 units reported problems in these areas (cold floor).

(3) Occupants may not observe the problem in they have carpet.

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3.1.2 (cont'd)
THERMAL BRIDGE TEST RESULTS

TYPE II: Overhang

(b) Townhouse overhang at end wall

e.g. Same as previous example.

EXAMPLE MEASURED: 1509 #11

TEMPERATURE MEASURED:

Indoors 21°C Outdoors: -8°C Surface: 5°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) -2°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: -4°C

PREDICTED PERIOD OF CONDENSATION 65 days

Comments

(1) Potentially serious thermal bridge.

(2) 2 of 8 units reported cold floors.

(3) Similar to II(a) but at overhang adjacent exposed shearwall aggravates the thermal bridge.

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3.1.2 (cont'd)
THERMAL BRIDGE TEST RESULTS

TYPE II: Overhang

(c) Townhouse overhang at end wall, with carpet

e.g. Same as previous example.

EXAMPLE MEASURED: 1509 #1

TEMPERATURE MEASURED:

Indoors 17°C Outdoors: -6°C Surface: 0°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) -10°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: 3°C

PREDICTED PERIOD OF CONDENSATION 133 days

Predicted outside temperature for frost on inside surface -7°C.

Predicted period of frost - 37 days.

Comments

(1) Same as II(b) except presence of carpet lowers surface temperature.

(2) Only one unit experienced frost under carpet (Photo 4.8). Due to carpet, moisture may not always reach slab or moisture is not observed.

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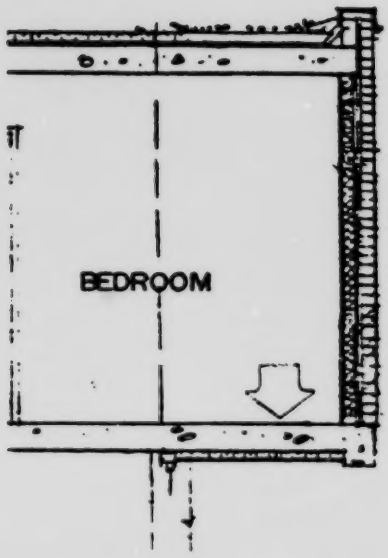
3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE III: Overhang

(a) apartment overhang

#1515 5, 4 & 3



EXAMPLE MEASURED: 1515 #5 (centre overhang)

TEMPERATURE MEASURED:

Indoors 17°C Outdoors: -12°C Surface: 6°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 5°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: -14°C

PREDICTED PERIOD OF CONDENSATION 10 days

Comments

(1) Thermal bridge of medium severity.

(2) 3 of 3 units reported problems in these areas.

(3) Condensation forms in 2" band on the inside perimeter of the overhang. The relatively long length of the overhang allows cooler surface temperature of the thermal bridges, because conduction heat along the slab is not as effective. Thermal bridging to the brick veneer is very good.

PRIMROSE CO-OPERATIVE

3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE III: Overhang

(b) Apartment overhang at end, or shearwall

e.g. Same as previous example.

EXAMPLE MEASURED: 1515 #5

TEMPERATURE MEASURED:

Indoors 17°C Outdoors: -12°C Surface: 3°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) +1°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: -8°C

PREDICTED PERIOD OF CONDENSATION 34 days

Comments

(1) More serious condensation potential than III(a).

(2) 2 of 2 corner units reported problems in this area.

(3) Same as III(a) except good conduction to exposed end of shearwall aggravates thermal bridge. There should be a thermal break between shear wall and slab overhang.

PRIMROSE CO-OPERATIVE

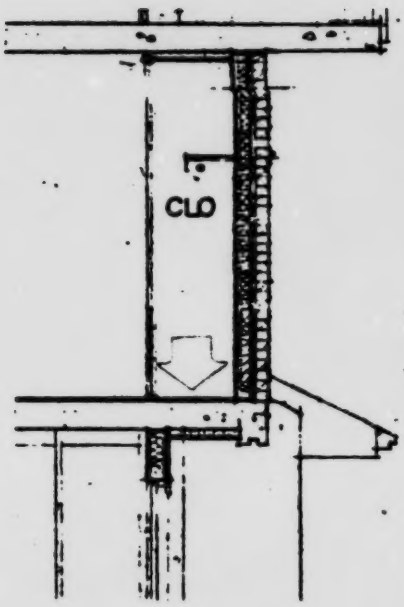
3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE III: Overhang

(c) Closet overhang

e.g. All closet floors in 2 bedroom townhouse.



EXAMPLE MEASURED: 1507 #6

TEMPERATURE MEASURED:

Indoors 23°C Outdoors: -12°C Surface: 4°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) -2°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: -4°C

PREDICTED PERIOD OF CONDENSATION 61 days

Comments

(1) Potentially serious condition. Lack of air circulation promotes colder surface temperatures.

(2) 6 of 11 units reported problems in this area.

(3) Condensation occurs in a 2" band along the inside perimeter of the overhang.

(4) Some units may also experience leakage through wall from balcony above; brick in this area exhibits serious wetting.

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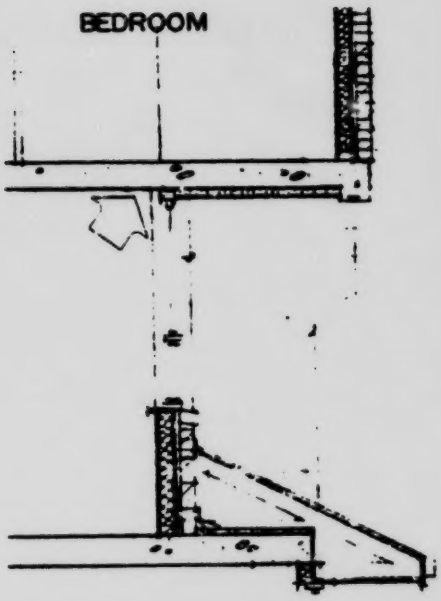
3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS



TYPE IV: Ceiling Beside Overhang

(a) Centre unit

e.g. - All master bedroom ceilings in 3 bedroom townhouses.
- All foyer ceilings in 2 and 3 bedroom townhouses.

EXAMPLE MEASURED: 1509 #1

TEMPERATURE MEASURED:

Indoors 19°C Outdoors: -1°C Surface: 15°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 11°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) No damage reported in this area.

PRIMROSE CO-OPERATIVE

3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE IV: Ceiling Beside Overhang

(b) Same as previous example except adjacent to end or shear wall.

EXAMPLE MEASURED: 1509 #11

TEMPERATURE MEASURED:

Indoors 22°C Outdoors: -8°C Surface: 15°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 11°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) No damage reported in this area.

PRIMROSE CO-OPERATIVE

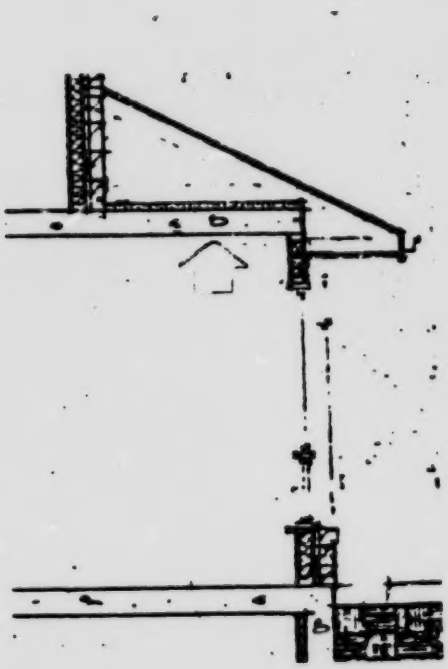
3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE V: Extended Ceiling

(a) Centre units

e.g. - All first floor and second floor ceilings in 3 bedroom townhouses.
- All first floor ceilings in 2 bedroom townhouses.



EXAMPLE MEASURED: 1509 #1 (centre ceiling)

TEMPERATURE MEASURED:

Indoors 17°C Outdoors: -6°C Surface: 12°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 11°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) 1 of 23 units reported problems in this area.

(2) Mold on ceiling was observed.

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3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE V: Extended Ceiling

(b) Same as previous example except adjacent to end or shear wall.

EXAMPLE MEASURED: 1509 #1

TEMPERATURE MEASURED:

Indoors 17°C Outdoors: -6°C Surface: 5°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) -1°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: -5°C

PREDICTED PERIOD OF CONDENSATION 52 days

Comments

(1) Potentially serious thermal bridge.

(2) 1 of 8 reported problem in this area (mold on ceiling).

(3) Exposed endwall can aggravate existing thermal bridge (as III(b)).

PRIMROSE CO-OPERATIVE

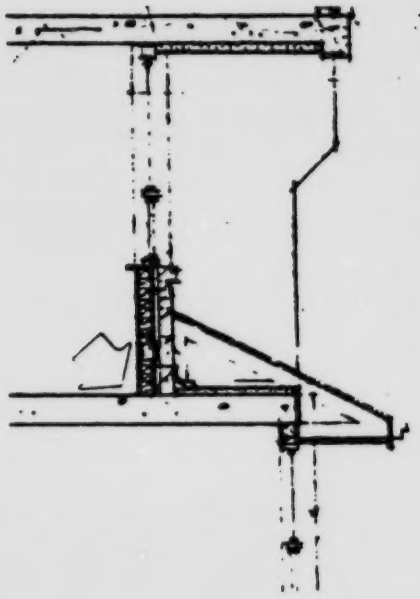
3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE VI: Floor Above Extended Ceiling

(a) Centre units

e.g. - Master bedroom and bedroom 3 floors in 3 bedroom townhouse.
- Bedroom 2 floors in 2 bedroom townhouse.



EXAMPLE MEASURED: 1509 #1

TEMPERATURE MEASURED:

Indoors 18°C Outdoors: -6°C Surface: 17°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION 18°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) No damage reported in this area.

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3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE VI: Floor Above Extended Ceiling

(b) Same as previous excample except at endwall or exposed shearwall.

EXAMPLE MEASURED: 1509 #1

TEMPERATURE MEASURED:

Indoors 20°C Outdoors: -6°C Surface: 7°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 0°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: -7°C

PREDICTED PERIOD OF CONDENSATION 37 days

Comments

(1) Potentially serious thermal bridge.

(2) 1 of 12 corner units reported damage in this area.

(3) Similar to VI(a) except proximity to end of shearwall aggravates thermal bridge (as III(b)).

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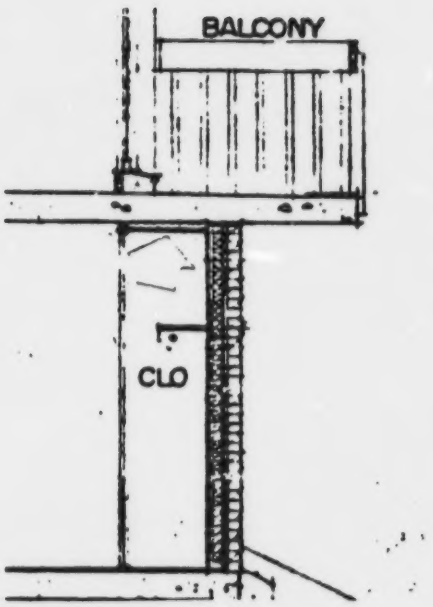
3.1.2 (cont'd)
THERMAL BRIDGE TEST RESULTS

TYPE VII: Ceiling With Exposed Surface Above

(a) Insulated part

e.g. - Closet ceiling in 2 bedroom townhouse.
- Living room ceiling in 2 bedroom apartment.



EXAMPLE MEASURED: 1507 #6

TEMPERATURE MEASURED:

Indoors 23°C Outdoors: -12°C Surface: 13°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 9°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) Marginal thermal bridge at normal conditions.

(2) 4 of 23 reported problems in this area, this may be due to leakage from the balconies above as serious brick wetting was observed in this area. (Photos 4.6 and 4.7.)

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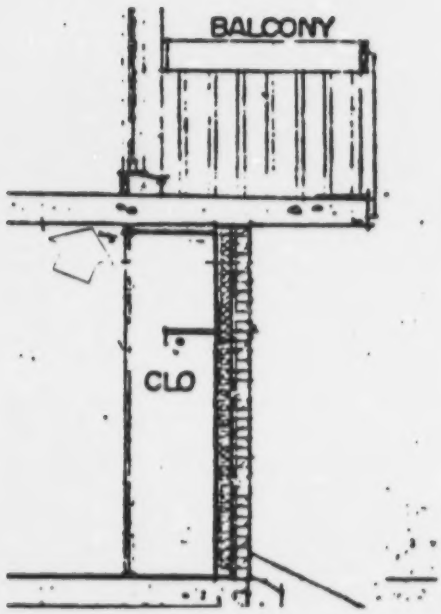
3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE VII: Ceiling With Exposed Surface Above

(b) Uninsulated part

e.g. Same as previous example.



EXAMPLE MEASURED: 1507 #6

TEMPERATURE MEASURED:

Indoors 23°C Outdoors: -12°C Surface: 14°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 10°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) Marginal thermal bridge at 40% R.H. At higher humidity levels may exhibit moisture problems.

(2) Mold, water marks observed on surface in 2 out of 12 units.

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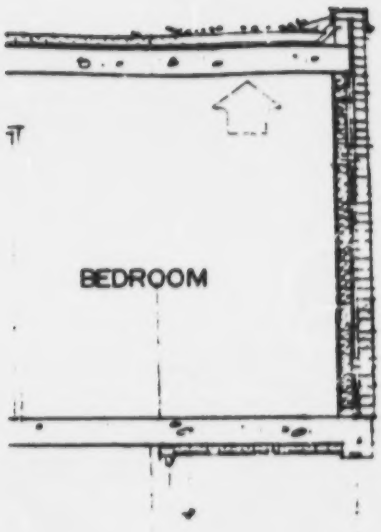
3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE VIII: Top Floor Ceiling

(a) Centre unit

e.g. - 1 bedroom apartment ceiling
- 2 bedroom apartment ceiling.



EXAMPLE MEASURED: 1505 #1

TEMPERATURE MEASURED:

Indoors 17°C Outdoors: -8°C Surface: 11°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 10°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) Marginal thermal bridge of normal conditions.

(2) Total 5 of 18 units reported problems in this area.

(3) Mold on ceiling due to high humidity levels.

PRIMROSE CO-OPERATIVE
3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE VIII: Top Floor Ceiling

(b) Same as previous example except adjacent to exposed end wall.

EXAMPLE MEASURED: 1515 #2

TEMPERATURE MEASURED:

Indoors 16°C Outdoors: -6°C Surface: 6°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 2°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: -9°C

PREDICTED PERIOD OF CONDENSATION 31 days

Comments

(1) Potentially serious thermal bridge, especially with higher humidity at ceiling level.

(2) 7 of 8 units reported problem in this area.

(3) Mold occurred in a strip a foot or more inside along perimeter of ceiling.

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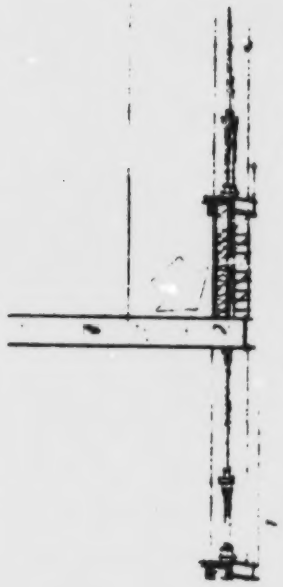
3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE IX: Slab Edge

(a) Centre units

e.g. Living room floor in
2 bedroom apartment



EXAMPLE MEASURED: 1505 #5

TEMPERATURE MEASURED:

Indoors 21°C Outdoors: -1°C Surface: 16°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 11°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) 4 of 9 units reported problem.

(2) Reported wetness is apparently due to run-off of condensate from window above.

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3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE IX: Slab Edge

(b) Same as previous example except adjacent to exposed end wall.

EXAMPLE MEASURED: 1505 #1

TEMPERATURE MEASURED:

Indoors 17°C Outdoors: -6°C Surface: 5°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) -1°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: -5°C

PREDICTED PERIOD OF CONDENSATION 52 days

Comments

(1) Potentially serious thermal bridge.

(2) No problems reported in this area.

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3.1.2 (cont'd)
THERMAL BRIDGE TEST RESULTS

TYPE X: Balcony and Fire Exit Door Frame

e.g. - All balcony door frames in
1 bedroom apartment and
2 bedroom apartments.
- All fire exit door frames in
2 bedroom apartments.

EXAMPLE MEASURED: 1505 #4

TEMPERATURE MEASURED:

Indoors 21°C Outdoors: 1°C Surface: 12°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION(-20°C) 2°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: -8°C

PREDICTED PERIOD OF CONDENSATION 34 days

Comments

(1) Thermal bridging potential.

(2) 3 of 15 reported condensation and frost problems in this area.

(3) 8 of 15 units reported draft from door.

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3.1.2 (cont'd)

THERMAL BRIDGE TEST RESULTS

TYPE XI: Balcony Side Window

e.g. All balcony side windows in 2 bedroom apartments.

EXAMPLE MEASURED: 1505 #4

TEMPERATURE MEASURED:

Indoors 22°C Outdoors: 1°C Surface: 15°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 7°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: N/A

PREDICTED PERIOD OF CONDENSATION N/A

Comments

(1) Marginal Thermal bridging at normal conditions.

(2) 4 of 11 units reported problems.

(3) Problems included condensation, rusting and paint peeling of frame, and frost.

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3.1.2 (cont'd)
THERMAL BRIDGE TEST RESULTS

TYPE XII: Window Frames

e.g. Windows in all units.

EXAMPLE MEASURED: 1505 #4

TEMPERATURE MEASURED:

Indoors 21°C Outdoors: 1°C Surface: 14.5°C

PREDICTED SURFACE TEMPERATURE AT DESIGN CONDITION (-20°C) 5°C

PREDICTED OUTSIDE TEMPERATURE FOR CONDENSATION AT INSIDE SURFACE: -15°C

PREDICTED PERIOD OF CONDENSATION 8 days

Comments

(1) Modest thermal bridging potential at normal conditions.

(2) Total 28 of 41 units reported having problems on windows.

(3) Significant condensation, first on frame, then on glass, occurred due to humidities higher than 40% R.H.

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3.2 Hygrothermograph Testing

The intent of this part of the study was to find out if there is any correlation between vertically integrated units and to record general temperature and humidity levels. It was thought that if a strong 'stack effect' existed the upper unit moisture level would be tracably influenced by that of the lower units.

3.2.1 Method

Based on preliminary damage reports and permission from occupants, the three bedroom townhouses, 1509 #3 and #4 and the one bedroom apartment 1515 #3, which is directly above the two townhouses, were chosen for this study. A hygrothermograph was placed in each of the master bedrooms in the two townhouses and in the living room of the one bedroom apartment. The fourth hygrothermograph was placed in the apartment corridor.

As relative humidity is a function of the temperature, it does not give a true picture of the amount of moisture in the air. For this reason, the grams of moisture per kilograms of dry air is used as the comparative measure. The g/kg value is determined from the temperature and the relative humidity level recorded on the hygrothermograph chart. Records were obtained for a continuous 18-day period.

3.2.2 Results

After detailed examination, it was found that the moisture level in the one bedroom apartment was always higher than townhouse 1509 #4 except for one day in which it was only slightly lower. This is not true when compared with townhouse 1509 #3. The reason for this is probably that the pipe plenum in the one bedroom apartment is more directly connected to townhouse #4 rather than townhouse #3.

3.2.2 Results (cont'd)

Of all the data collected, the weekend of February 12 to 14 gives a better picture than any other period. Within this period, the occupant in the one bedroom apartment 1515 #3 left the unit and so there is no cause for moisture generation. However, it was found the moisture content in the apartment remained at approximately 3.2 grams of moisture per kilogram of dry air. This is significantly higher than the moisture level in the outside air (+/-1.0 g/kg. average). If the apartment is as well ventilated as is suggested by the tracer gas test, the apartment would be as dry as the outside condition after a short period. Because the moisture content level in the apartment is so close to townhouse #4, this (and also results from tracer gas test) suggest strongly that the stack effect plays a very important role in the high humidity levels of upper units.

The humidity level in the apartment common corridor remains relatively constant and seems to have no relationship with lower units.

3.3 Tracer Gas Testing (Infiltration and Stack Effect)

The objectives of this test procedure are to establish positively the existence of air movement between vertically related units, to establish the suspected route of such air movement, to establish, if possible, the approximate magnitude of such air movement and to obtain a measurement of the infiltration and exfiltration rates of typical units under natural conditions.

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3.3.1 Method

Tracer gas testing was selected over fan-depressurization testing as it will provide an accurate account of air volume changes under natural conditions. Fan-depressurization, on the other hand, would by its nature upset natural air flow patterns and rates.

Sulphur hexafluoride (SF_6) was selected as the tracer gas.

In order to provide results which could be related to other associated tests, units 1509 #3, 1509 #4 and 1515 #3 which were also equipped with hygrothermographs were selected as test sites.

The two lower units (townhouses, #1509 - 3 & 4) and the upper unit (Apt. #1515-3) were tested on seperate days, in order to obtain values of air change for each unit. In order to test for air change between lower and upper units, tracer gas samples were taken in the apartment living room, bathroom, pipe plenum, and the apartment corridor during tracer gas testing of the townhouse units.

For further details related to the test method the reader is referred to Appendix 6 which contains a report prepared by MacLaren Engineers Planners & Scientists Inc., the firm engaged to conduct these tests.

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3.3.2 Results

The following is excerpted without editing from the report prepared by MacLaren Engineers Planners and Scientists Inc. The entire report is contained in Appendix 6.

Conclusions

It should be noted that in both townhouse units, the third floor exhibits the highest concentrations of tracer gas, with the second floor next and the first floor showing the lowest concentrations. Although this trend is not great enough to skew the data, it does confirm a tendency for the air within the units to migrate from the lower levels to the upper floors with the stack effect. This tendency is also apparent in the movement of tracer gas through the pipe plenum into the upper apartment unit.

Analysis of the results of apartment no. 3 testing on February 5, 1982, shows that the pipe plenum appears to be a major route for air exchange from the townhouse units below. Tracer gas appears in the pipe plenum at a high level for the first sample. While the levels in the two townhouse units, for the first sample, range from 48.3 to 66.9 ppb, the level in the plenum at the same time is already at 44.5 ppb. In fact, the level within the pipe plenum peaks within the first half hour and then exhibits a decay curve similar to the two townhouses below. This suggests that a pipe plenum is a major source of air movement between the townhouse and the apartment.

SF_6 sampling in the bathroom and living room of the apartment as well as the outside corridor, also tends to verify this conclusion (see figure 2). If the plenum is a major source of influx for the apartment, it would be expected that SF_6 would travel from the plenum into the bathroom, into the living room, and finally into the outside corridor.

The data confirms this conclusion. The initial bathroom level is higher and reaches a peak, then begins to decay sooner than the levels in the living room. This time lag would be reversed or be less constant if there were another route of air entry from the units below.

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3.3.2 Results (cont'd)
NOTE: Excert from MacLaren Engineering Report - Appendix 6 (cont'd)

An air change rate of 0.63 air changes per hour was established for apartment 3 on February 10, 1982. This is a fairly high rate compared to the two townhouses below. A significant flow of air is exiting under the door (confirmed by a smoke pencil), which is not weatherproofed, as in the townhouses below.

Stale air within the apartment was noted on both days of testing. This would be inconsistent with the high air change rate unless a significant portion of the make-up air is being introduced from the townhouses below. What appears to be happening is that the lower townhouse units are fairly tight (0.2 air changes/hour), however, between these two units, a total volume of 111.37 m^3 of air per hour is exiting, while the apartment above is expelling approximately 70.16 m^3 per hour.

While it cannot be suggested that the total make-up air in the apartment is coming from the townhouses below, for the reasons stated above it appears that a significant portion is. It is impossible to quantify the volume of air moving into the upper apartment through the pipe plenum unless a comparative air change is performed with the pipe plenum open and closed.

It would appear, therefore, that although the air change rate for the apartment is significantly higher than the lower townhouse units, warm moist air entering from below and exiting from the apartment is contributing to the humidity problems being experienced in the apartment units.

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3.3.2 Results (cont'd)

Note: Not mentioned by the authors of this report is the difference in weather conditions on the two testing days. February 10th experienced winds of 17 km/h WSW, roughly twice the velocity and from a different azimuth than February 5th (9 km/h NE).

In order to estimate the rate of air exchange from the townhouses to the apartment, the data in Figure 2 may be analyzed using the equation

$$V \frac{dC}{dt} = F - QC$$

where V is the apartment volume (m^3)
C is tracer gas concentration (p.p.b.) of apartment
F is the injection rate (p.p.b. x m^3/hr.)
Q is the exfiltration rate (m^3/hr.)

If we assume the leakage path is virtually exclusive to the plumbing plenum then

$$F = Q'C_p$$

where Q' is the rate of leakage from lower to upper units (m^3/hr.)
C_p is the gas concentration in the plenum (p.p.b.)

$$Q' = \frac{1}{C_p} \quad V \frac{dC}{dt} + QC$$

The values calculated for various points range between 71.28 and 74.9 m^3/hr. which exceeds the exfiltration rate. This condition is unrealistic.

The exfiltration rate on February 5 was likely lower than on February 10 when the apartment exfiltration rate was determined since the wind direction on February 5 was toward the windows hence counter to stack effect (note gas detection in the corridor) whereas on February 10 the windows were on the leeward side, reinforcing the stack effect. Reducing the exfiltration rate in the analysis does not, however, substantially alter results that indicate most of the exfiltrating air from the apartment is supplied from the townhouses below.

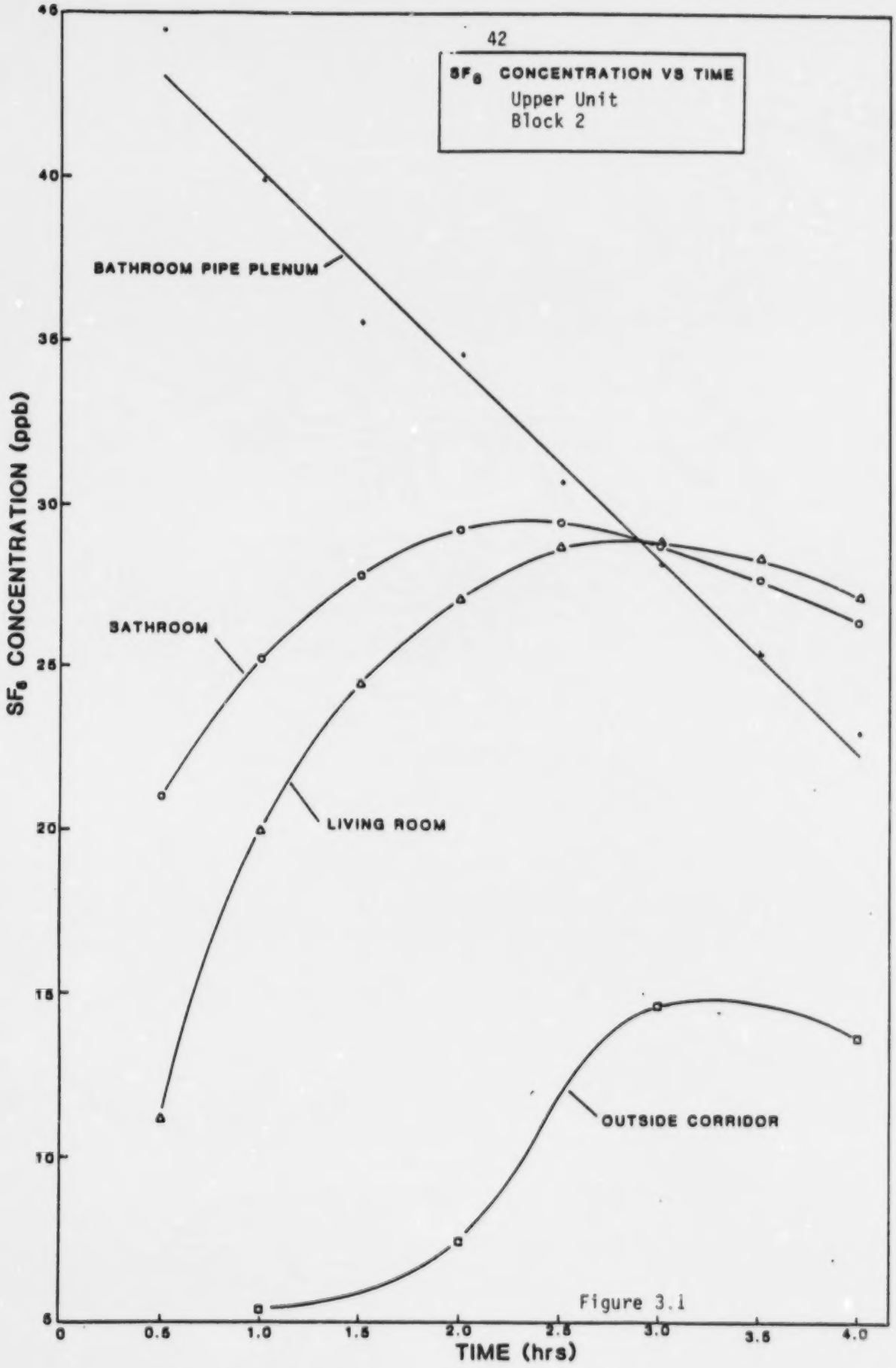

SF_6 CONCENTRATION VS TIME
Upper Unit
Block 2
BATHROOM PIPE PLENUM
BATHROOM
LIVING ROOM
OUTSIDE CORRIDOR
SF_6 CONCENTRATION (ppb)
TIME (hrs)
45
40
35
30
25
20
15
10
5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

Figure 3.1

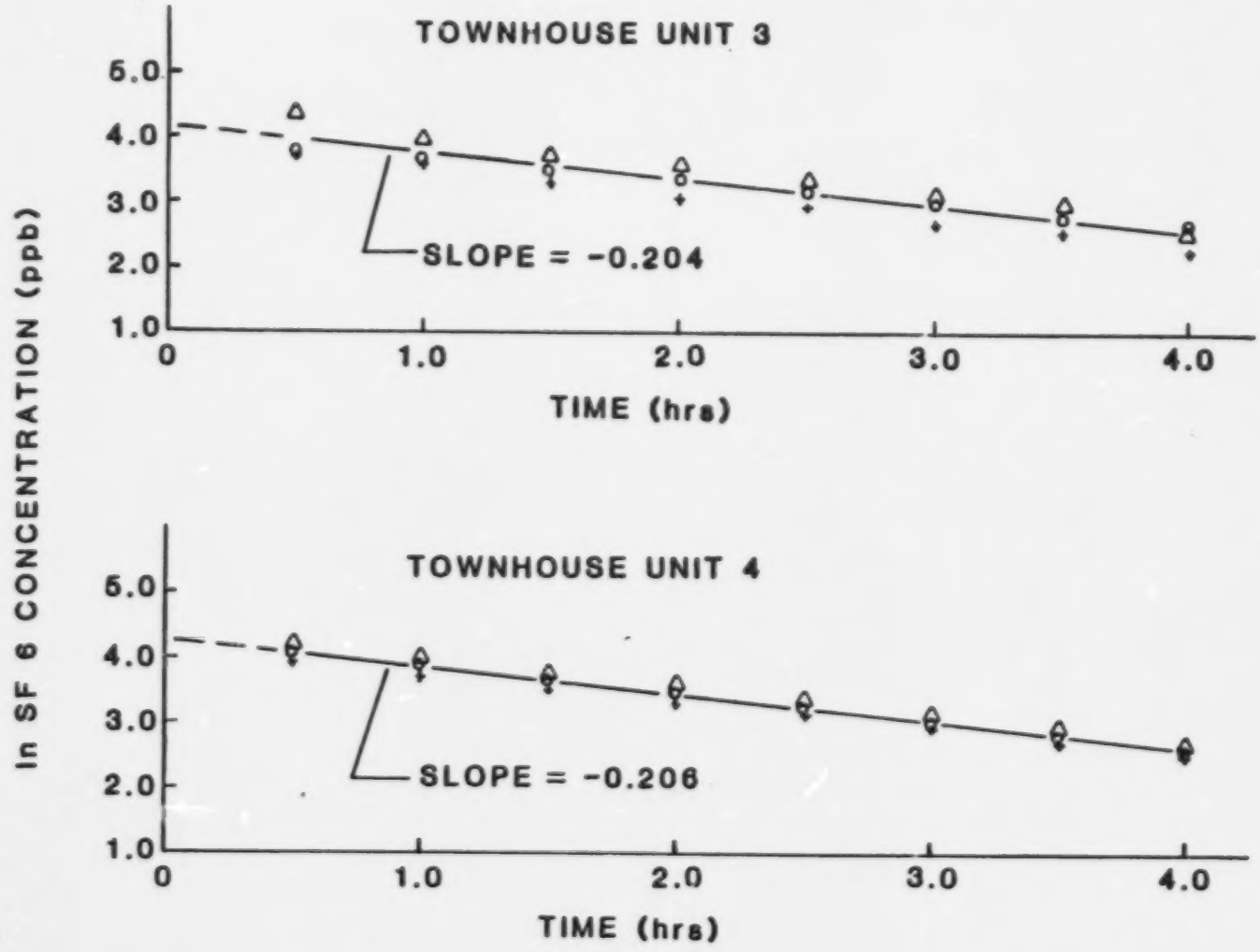
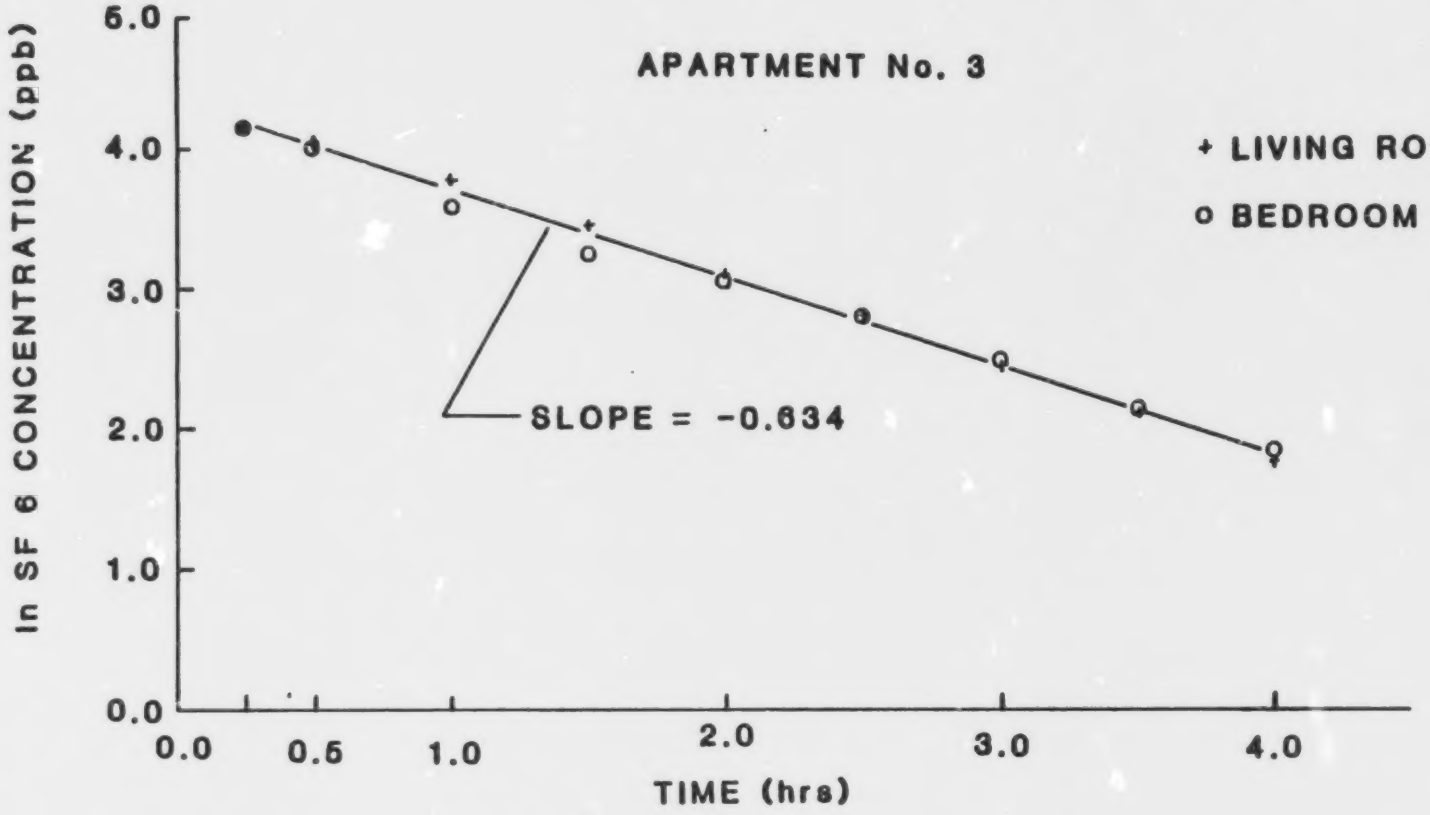


Figure 3.2

SF 6 TESTING 1541 DAVENPORT ROAD



SF 6 TESTING 1541 DAVENPORT ROAD

Figure 3.3

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3.4 Field Observations

3.4.1 Building Deficiencies

Field inspection of specific problem locations was made subsequent to testing and prior to selection of trial measures in order to obtain additional information on the nature and cause of deterioration (i.e. wetness or mould growth).

The building management also commissioned a study and report* by Morrison-Hershfield Ltd., Consulting Engineers, to investigate the structural, architectural, electrical, mechanical, roofing and waterproofing system to determine the existence of deficiencies. The report was based on field inspection and review of the available construction documents.

The following is a summary list of specific items with brief description and discussion as to their nature. The list is not comprehensive and contains only representative items which are, in the opinion of the authors, relevant to the topic of this study. Some items are drawn from field inspection by ALLEN-DRERUP-WHITE LTD. staff, others are drawn from the above report. The following list is for information purposes only and for specific description and comprehensive listing of the deficiencies the reader is referred to the above-mentioned report.

.1 Water Accumulation on Floor, Block 1
Upper Units (Type I Location)

Initially thought to be caused by condensation, the water disappeared when accumulated snow was removed from the balcony. On closer examination it was found that the balcony did not have a sloped surface (away from the wall) and that the exterior wall cavity flashing was carried directly to the top of the slab without any waterstop means installed at the base of the wall. See Photo 4.1.

Water damage here is due to water leakage, and contributes to high humidity levels by introducing quantities of water to the space and wetting interior building materials.

*Ref. 10 Morrison Hershfield Ltd. Report #18301401
September 23, 1983.

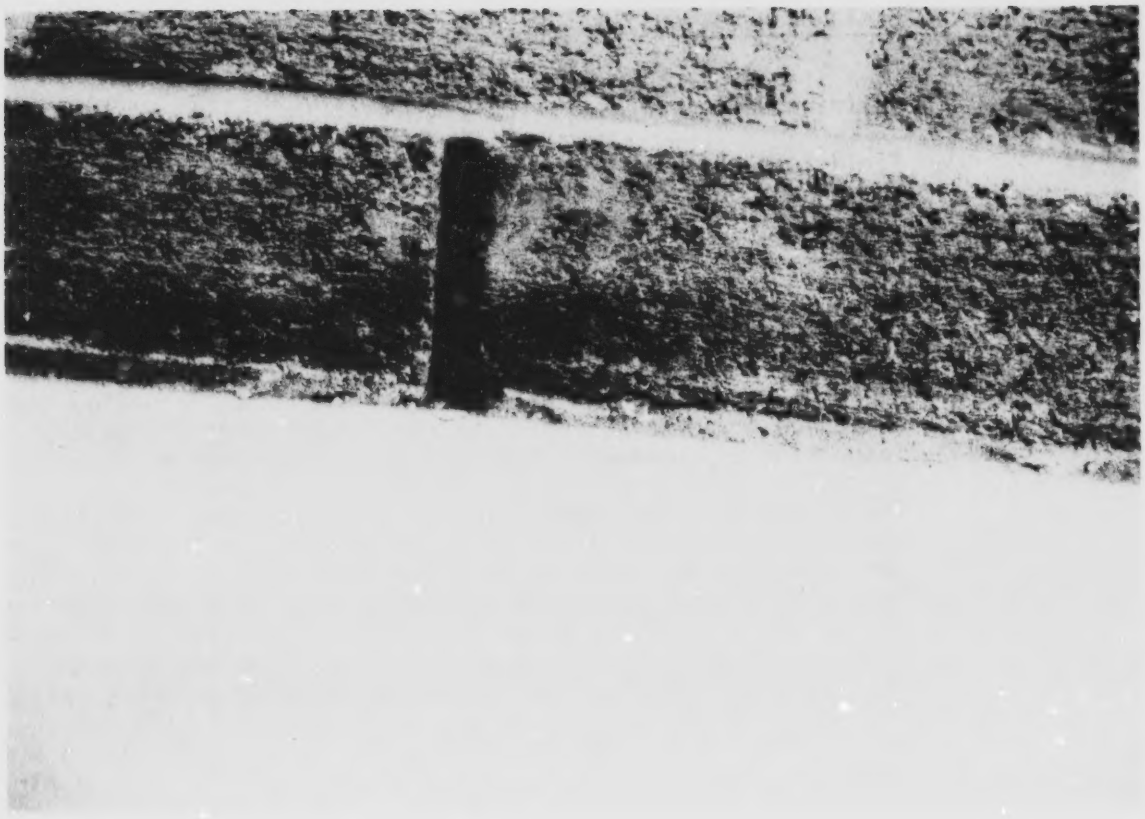

Photo 3.1 - Brick at Surface of Common Balcony 4th Level Block 1

Exterior masonry rests directly on unsloped balcony slab allowing water leakage into building.

See 3.5.1.1

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3.4.1 Building Deficiencies (cont'd)

.2 Water Leakage Into Apartment Corridor and Washrooms, East Wall Block 1

Caused by inadequate or improper wall construction, water leaks occur regularly at the floor level, soaking the carpeting.

.3 Insufficient Insulation, Lack of Vapour Barrier 1515-1

A test opening was made in a wall area that was badly deteriorated for no apparent reason. The opening found

- no vapour barrier
- 2" only of insulation
- no airspace behind brick (2 x strapping applied directly to brick)
- improperly installed flashing (would direct water inwards, not outwards)

This badly constructed wall section is apparently limited to a small area at an unusual juncture in the building (sloping roof level change). The deficient construction caused the drywall deterioration at this point, although the severity of deterioration may have been increased by high humidity levels.

.4 Missing Insulation On Shear Wall 1515-7

A test opening was made in an exterior wall which exhibited pronounced condensation. It was found that the wall (C.I.P. outside shearwall) was uninsulated, with the drywall being directly adhered to the concrete.

Condensation and damage is due to absence of insulation, which is present on other, similar walls.

3.4.1 Building Deficiencies (cont'd)

.5 Water Leakage at Basement of 1509-1, Block 2

Apparently due to openings from formwork ties which were not patched during construction, or failed or improper dampproofing. Water entry is a problem of this unit and several others.

Water entry of this nature often creates or contributes to high humidity levels by adding moisture to the air and soaking interior building materials. Hygrothermograph testing, however, did not show this unit to have higher moisture levels than other similar units.

.6 Exterior Door Seriously Warped and Delaminated

An exterior door leading to the common balcony on the 4th (top) level of block 1 is seriously damaged and warped (approximately 1-1/2" warpage).

The opening also has an aluminum storm door installed on the exterior, over the solid door in question. Due to stack effect, the position of the opening at the top of the building, and the poor fit of weatherstrip, exfiltration of air around the perimeter of the door was more or less constant. During cold weather, moisture contained in the exfiltrating air condensed between the storm door and the solid door, wetting the surface of the solid door (see Photo 3.2). While the rapid deterioration of the door is due to its particle-board construction (not acceptable for exterior use) and the lack of paint on top and bottom stiles (which would have retarded water entry), it is probable that any wood door would eventually suffer damage due to more or less constant wetting of its interior surface during the winter months.

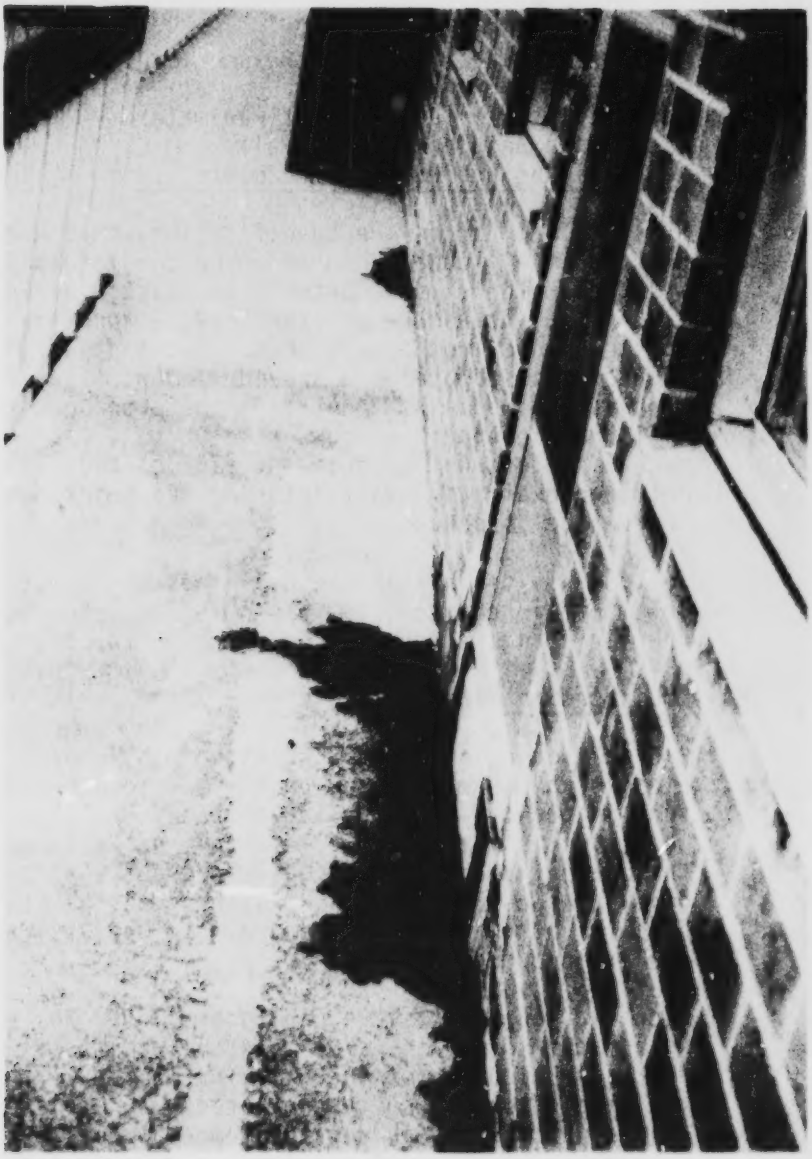

Photo 3.2 - Common Balcony 4th Level
Block 1

Water from air leakage around inner door condenses behind storm door.

See 3.5.1.6

3.4.1 Building Deficiencies (cont'd)

.7 Lack of Interior Caulking at Perimeter of Windows and Doors and at all Wall/Ceiling and Wall/Floor Joints

While called for in the specifications this work was omitted in all cases when an inspection of this item was made. There is no detectable leakage at wall/ceiling joints as the plaster/drywall junction is quite tight and does not show cracks. Substantial air-leakage occurs at baseboards and around windows. Air leakage around windows is apparent from the pronounced effloresence around windows (see Photo 5.1). As this mechanism does not produce interior surface damage it has not been examined. Wall interior and brick damage may however be suspected.

Testing was shown that the buildings exhibit a very low level of air change. If this omission were rectified, the air change rate would be further reduced.

.8 Moisture in Exterior Closets

Block 2 lower units (1509) contain master bedroom closets which are exposed on 4 sides to exterior surfaces, that is the top (balcony above) back, one side and floor. Detailing is poor at this location and water runoff from the balcony above is not controlled and wets the exterior brick of the closet walls. Flashing at the base of the brick is poor and is not turned into the wall at the reglets provided.

Accumulation of moisture on closet floors was evident in a number of units. The moisture was most severe near the baseboard of the exterior wall. It appears that the concrete and masonry create an efficient thermal bridge which produces surface temperatures $10^{0}C$ or more below indoor temperatures (location type III-c). On cold days the floor temperature can dip significantly beloww the dew point, causing condensation. Residents often combat the problem by covering the floor with items ranging from newspapers to luggage, thus reducing slab temperatures further.

Leakage of water from the balcony above may also be responsible for some water damage but observation has not been able to confirm this, even at times when the exterior brickwork was visibly soaked. Reports of water presence other than during cold periods have not been received.

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3.4.1 Building Deficiencies (cont'd)

.9 Thermal Dusting & Mould Formation at Stud Lines of Exterior Walls

Patterns of "thermal dusting" and mould growth were noted in many units corresponding to the locations of exterior wall studs.

The exterior wall system did not utilize an exterior or interior insulating sheathing material in order to "thermally break" the studs, as was recommended practice at the time and is presently a requirement for co-operative housing using metal studs.

3.4.2 Miscellaneous Observations

The following is a summary list of typical observations made during the testing program.

- Efflorescence around window edges on the leeward side of the building in the upper units and at townhouse upper floor windows.
- Smoke test indicated exfiltration from windows in the upper units (e.g. 1515 #4).
- Smoke tests indicated infiltration from bathroom pipe plenum in upper units (e.g. 1515 #5).
- Smoke tests indicated exfiltration to bathroom pipe plenum in lower units (e.g. 1509 #1).
- Mould on top floor ceiling in many of the units, some extends as far as one foot from the wall (e.g. 1505 #4).
- Mould on ceiling and condensation on floor in extended closet of two bedroom townhouse (e.g. 1507 #6).
- Condensation on inside surface of windows in most of the upper levels.
- Condensation on balcony door and fire exit door frames in two bedroom apartments (e.g. 1505 #4).
- No noticeable condensation in three bedroom townhouses.
- Frost on floor overhanging entrance door of three bedroom townhouses, (e.g. 1509 #1).

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3.4.2 Miscellaneous Observations (cont'd)

- Water damage, condensation and frost buildup along floor edge in one bedroom apartments (e.g. 1515 #5).

- Water leakage onto floor in two bedroom apartments from balcony and/or from condensate dripping down the window (e.g. 1505 #5).

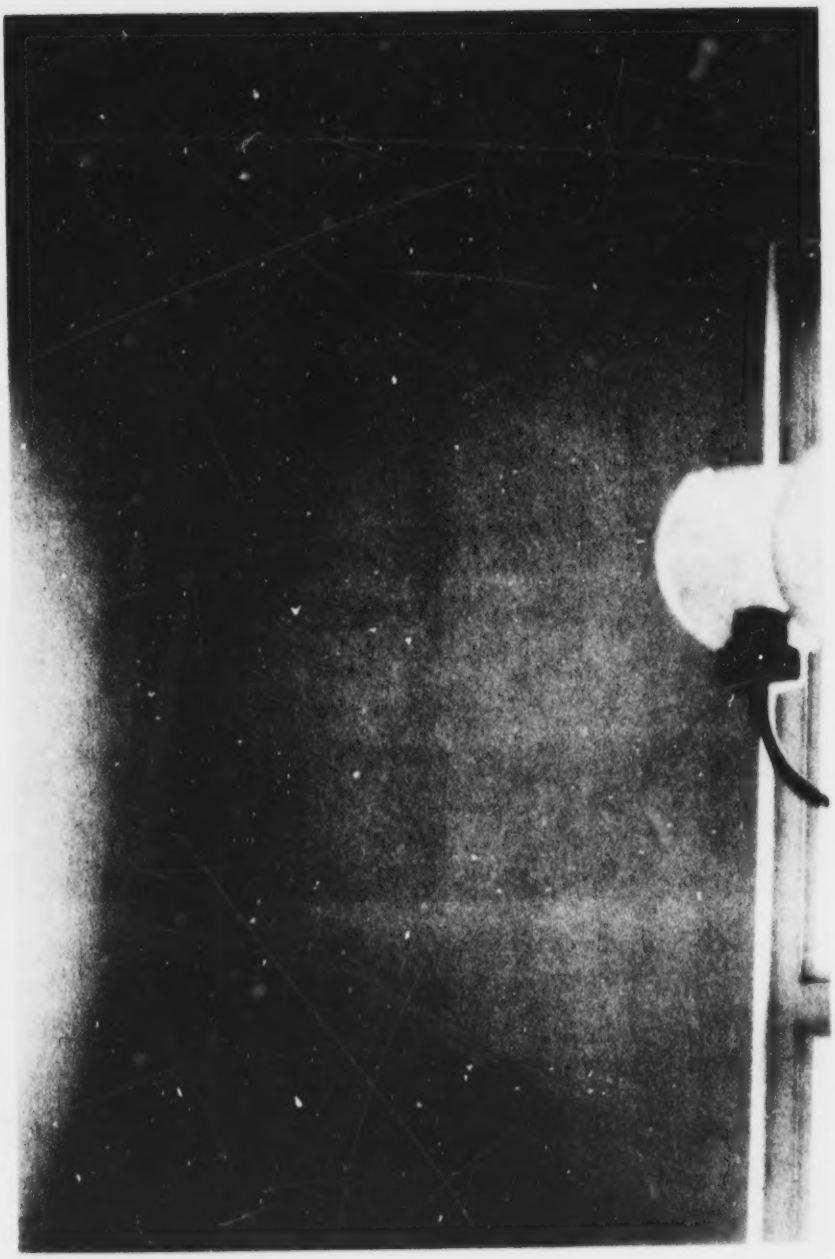

Photo 3.3

Marking over exterior wall studs

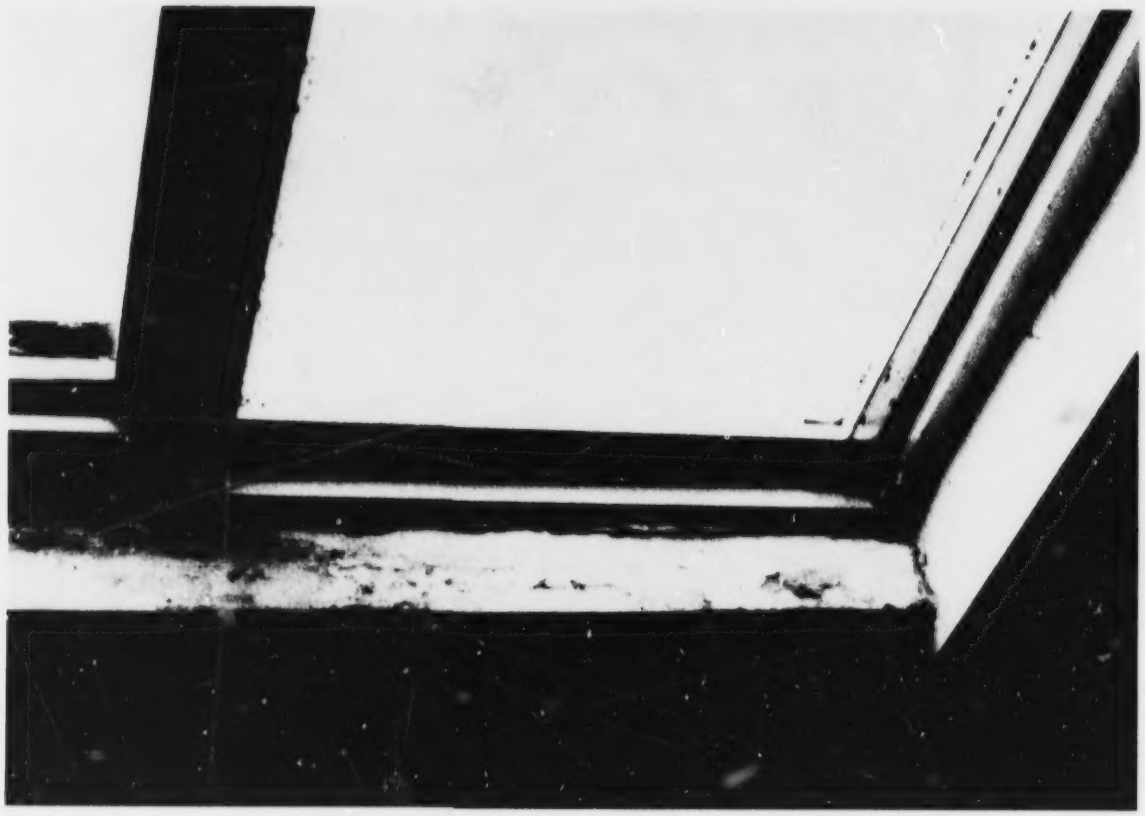

Photo 3.4 - Window-sill Typical Aluminum Slider

Deterioration of drywall return from water condensed on window frame and glass.

Photo 3.5 - Window Sill - Fixed in Aluminum Frame

Condensing water from door and window frames sufficient to cause serious interior finish deterioration.

Location Type XI

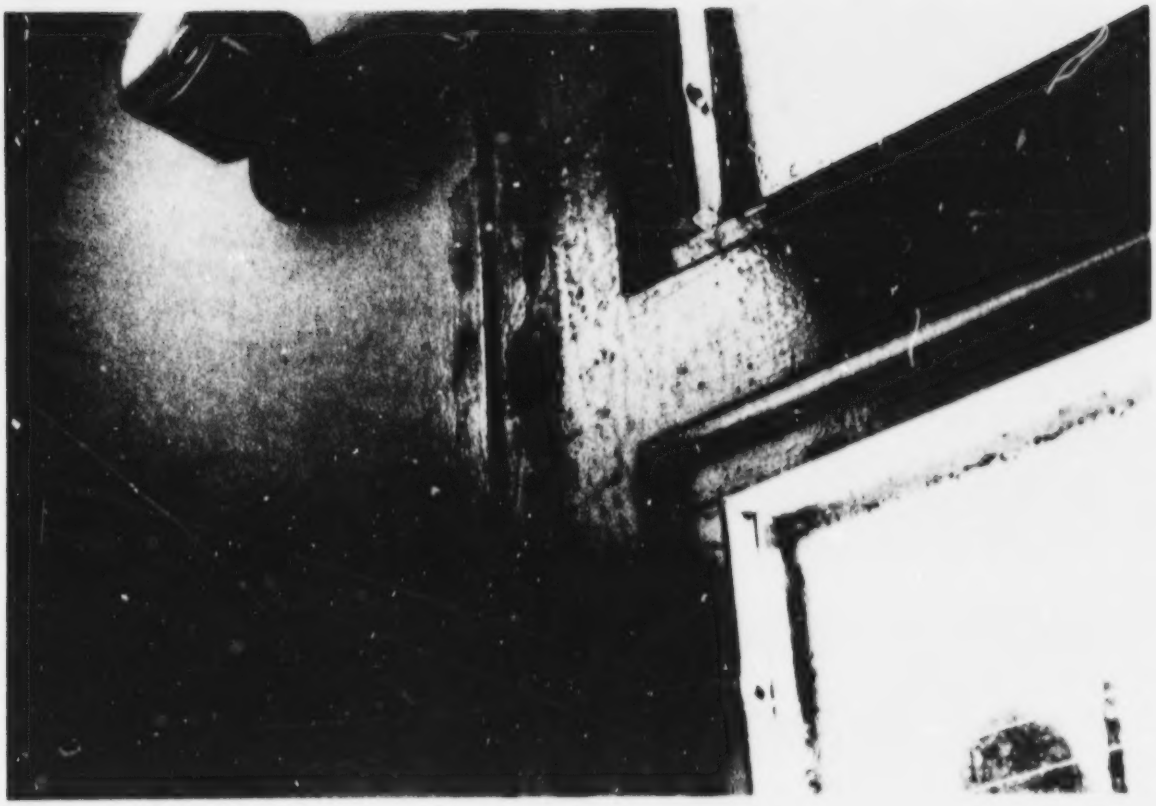

Photo 3.6 - Steel Window and Door Frame

Exterior steel door and window frame showing condensation paint peeling and rust.

Location Type X

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SECTION 4.0 CORRECTIVE TRIAL MEASURES

4.1 General

The previous Section 4.0 identified a series of significant problems which contribute to the moisture/condensation damage at Primrose Co-operative. These can be summarized as follows:

1) Thermal Bridges - Low temperatures occurred at slab edges and overhangs, aggravated by the location of closets, and intersection with exposed shearwalls.

2) Door Frames - Non thermally broken steel door frames exhibited low surface temperatures.

3) Window Frames - Marginal thermal breaks yielded inside surface temperatures lower than glass temperatures.

4) Tightness/Air Leakage - The overall level of air change was found to be very low.

5) Stack Effect - An air movement pattern from lower units to upper units was identified resulting in higher humidity levels in upper units.

6) Ventilation - Existing mechanical ventilation (occupant controlled) was found not to be used for general ventilation, contributing to low overall air-change rates.

In discussion with CMHC, the Co-operative and Ministry of Municipal Affairs and Housing officials, a program of trial measures was struck after analysis of various options according to their overall cost, as applied to the buildings as a whole. The overall budget of $25,000.00 proved to be restrictive in selecting a program and a 'less than optimum' compromise approach was taken for this reason.

4.2 Selection of Measures

In the process of selecting measures to alleviate the problems identified, the reader should be aware of the basic interrelationship of the problem areas, that is, thermal bridges relative to air change.

Thermal bridges become problematic when their interior surface temperature is sufficiently low to cause condensation. This temperature will vary with the air moisture level; the lower the moisture level is the lower the surface temperature may be without causing condensation.

Moisture level is a function of moisture production (e.g. showers, water entry from outside) and the rate at which it is removed by the replacement of indoor air by outside air, i.e. the ventilation rate. For a given moisture production rate, the moisture level can be reduced by increasing the ventilation rate.

In examining the various thermal bridges it became clear that a large number were marginal, (i.e. window frames types XI and XII) and others would require extensive and costly retrofit (i.e. door frames, type X). If moisture levels could be controlled to levels below that which would result in condensation on these surfaces, the scope of remedial measures could be reduced significantly.

Based on this a target moisture level of 25% R.H. @ 20°C indoor was selected (4.0 grams H_2O/kilogram dry air). As shown in 'Case A' following, however, the program of remedial measures which resulted from this target exceeded the available budget of $25,000 by at least 100%. Further cost analysis (cases 'B and C') yielded the conclusion that:

1) Moisture levels would have to be reduced to 20% R.H. @ 20°C in order to reduce the number of thermal bridges requiring treatment

2) Automatic control of ventilation was not possible.

During the selection of measures the question arose as to the merits of two possible treatments of structure thermal bridges being a) slab heating and b) exterior insulation.

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4.2 Selection of Measures (cont'd)

CASE 'A'

This case assumes that ventilation levels will be controlled to approximately 25% R.H. at 20°C, and includes for automatic control of ventilation.

*Slab Heating:	- excluding closets		$13,500.00
	- extra if closets included		4,000.00
Air Sealing:	- Block 2:	$ 4,000.00	
	- Block 1 :	6,300.00	
		$10,300.00	$10,300.00
Closet Relocation:			3,000.00
Ceiling Insulation:			
- Type V-b	8 units:	$ 4,000.00	
- Type VIII-b	9 units:	9,000.00	
		$13,000.00	13,000.00
Ventilation:			
- Basement fan switches 14 units Block 2:		$ 700.00	
- Allowance for dehumidistat for above:		2,100.00	
- Dehumidistats Block 2 upper (7) units:		875.00	
- Dehumidistats Block 1 lower (11) units:		1,975.00	
- New fans and dehumidistats Block 1 upper units:		5,500.00	
		$11,150.00	$11,150.00
Total Excluding Slab Heating at Closets:			$50,950.00
Total Including Slab Heating at Closets:			$54,950.00

*Locations:

Type IX - b
Type VI - b
Type III - c (closets)
Type II - c and b

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4.2 Selection of Measures (cont'd)

CASE 'B'

This case assumes that ventilation levels will be controlled to approximately 20% R.H. at 20°C, and includes for automatic control of ventilation.

*Slab Heating:	- excluding closets		$ 4,000.00
	- extra if closets included		4,000.00
Air Sealing:	- Block 2:	$ 4,000.00	
	- Block 1:	6,300.00	
		$10,300.00	$10,300.00
Closet Relocation:			3,000.00
Ceiling Insulation:			
- Type V-b	8 units:		4,000.00
Ventilation:			
- as per Case 'A'			11,150.00
Total Excluding Slab Heating at Closets:			$32,450.00
Total Including Slab Heating at Closets:			$36,450.00

*Locations:

Type III - d (closets)
Type II - c and b

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4.2 Selection of Measures (cont'd)

CASE 'C'

This case assumes that ventilation levels will be controlled to approximately 20% and is based on non-automatic controls.

Slab Heating: - excluding closets	$ 4,000.00
- extra if closets included	4,000.00
Air Sealing: As per cases 'A' and 'B':	10,300.00
Closet Relocation:	3,000.00
Ceiling Insulation:	
- Type V-b 8 units:	4,000.00
Ventilation:	
- Install speed controls each unit 43 units x $50.00	2,150.00
- Provide temperature and humidity dial indicators 43 units x $15.00	645.00
Total Excluding Slab Heating at Closets:	$24,095.00
Total Including Slab Heating at Closets:	$28,095.00

*Locations:

Type III - d (closets)
Type II - c & b

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4.2 Selection of Measures (cont'd)

Analysis for cost vs. benefit was performed for two locations being III-c (closet) and II-c (overhang at shearwall) a description of which is included as Appendix 7. The analysis results were in favour of insulation for the closet location and in favour of heating for the overhang location.

An example of each trial measure contemplated was put in place during December 1982 and January 1983 in order to obtain an evaluation of each on a success/failure basis.

A description of each trial measure follows:

1) The closets in block one were, in three separate cases:

   a) Relocated to allow circulation of air
   b) Flashed to prevent suspected water leakage
   c) Insulated at the thermal bridge.

   A fourth closet was fitted with all three modifications cited above.

2) A slab-overhang thermal-bridge location was fitted with a slab heating element.

3) The mechanical penetrations at the third floor of block two were sealed against air movement.

4) Basement exhaust fans in the lower units of block two were wired to permit continuous operation and exhaust fans in upper units of block two were wired using a speed control permitting variable operation by the occupants.

The total expenditure to put these measures in place was $8,780.

Monitoring was carried out during the balance of the 1983 winter season and during the 1984 heating season; the results are detailed in this section.

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4.3 EXTEROR CLOSETS

4.3.1 General

The exterior wall closets of 1507 (block 1, type III-C) have all experienced some degree of damage due to moisture. Surface temperature measurements gave a predicted condensation period of 61 days at the floor slab, but predicted no condensation on the walls. Significant wall damage was evident in most units, however, and it was surmised that this additional damage might be resulting from:

a) Leakage from the balcony above (the water runoff control is poor)

b) Lack of air circulation leading to reduced air temperatures adjacent to the wall surfaces.

Not being able to eliminate any of the three potential causes it was decided to treat all three on a trial basis. The program struck was as follows:

1st unit - Insulate floor, shear wall and slab edge to (1507-1) correct low slab temperature.

2nd unit - Relocate closet to interior partition to allow (1507-7) improved air circulation.

3rd unit - Flash balcony edge above and at line of lower (1507-4) roof at brick to correct potential water entry.

4th unit - All the above changes were made. (1507-2)

Drawings 1, 7-1, 7-2, 7-3, 7-4 and 7-5 following show the modifications made.

During the following winter insufficient periods of prolonged cold weather were encountered to allow a qualitative judgement of effect to be made. On one occasion water accumulation was noted on the floor of the unit where flashing, to prevent water entry, was carried out. It is probable that the first attempt at flashing did not address the actual route of water penetration.

To provide more conclusive information, further study was carried out in early 1984 as follows:

1) Measurement of slab temperatures
2) Verifying performance of flashing retrofit
3) Qualitative observation.

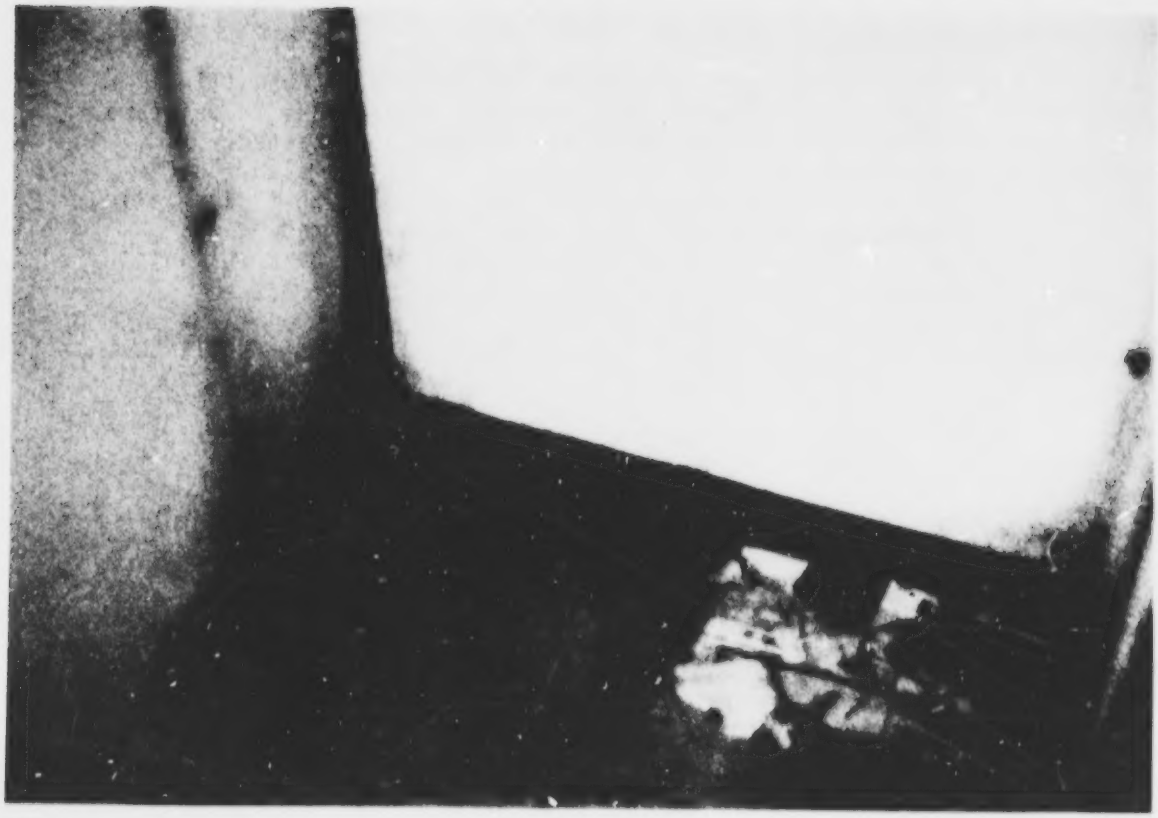


Photo 4.1 - Interior View, Exterior Closet

Interior view showing mould accumulation
on floor and at wall studs.

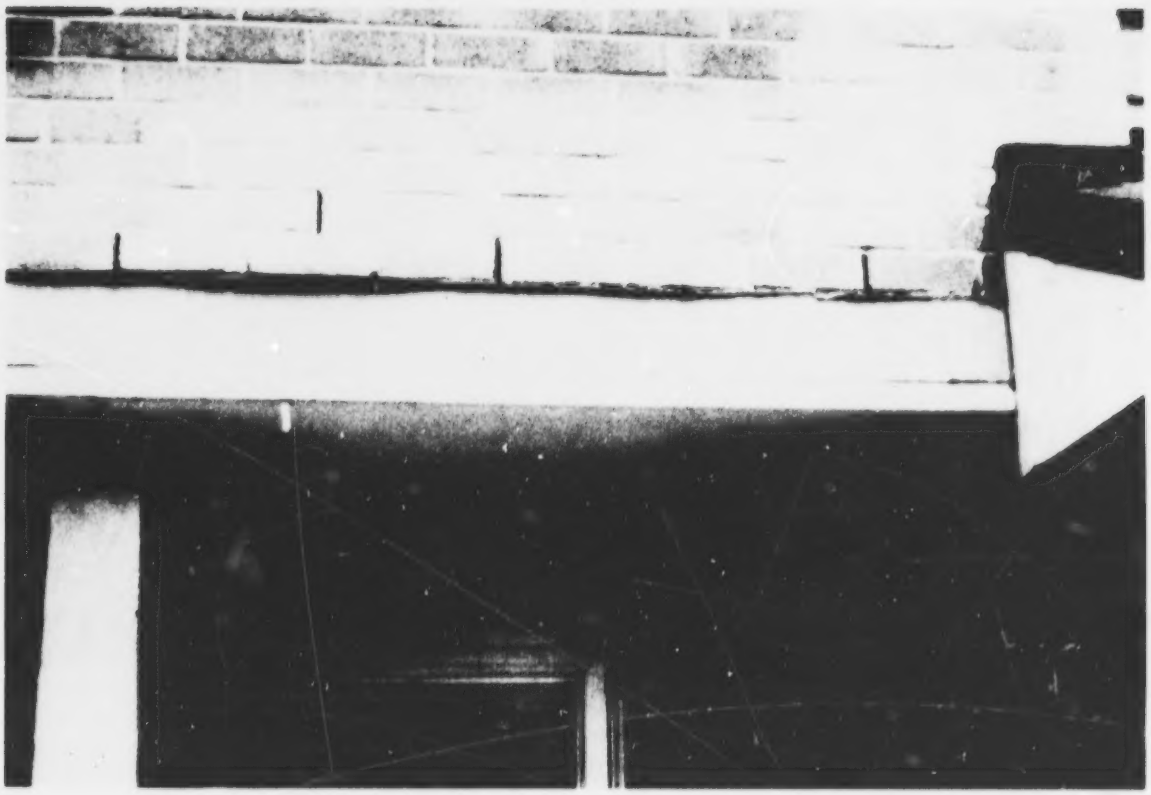


Photo 4.2 - Exterior View, Closet Prior to Insulation

Exterior view prior to installation of slab edge, soffit and shearwall insulation.

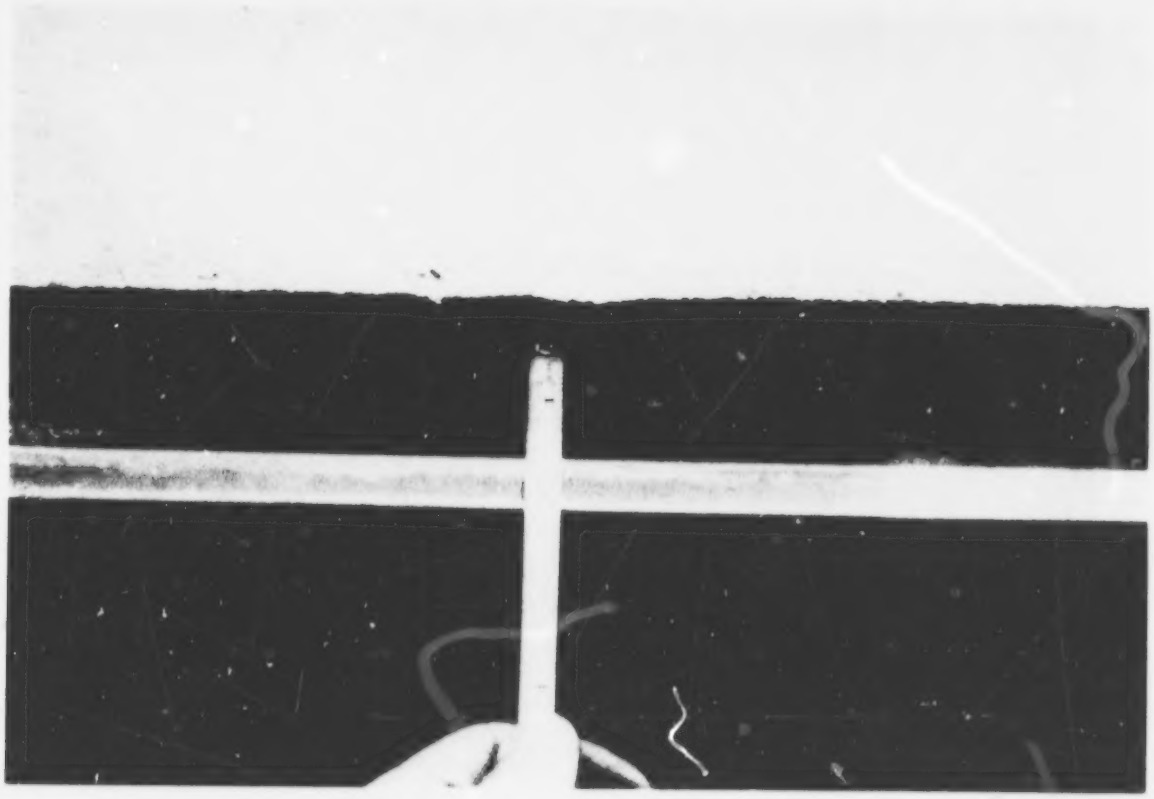
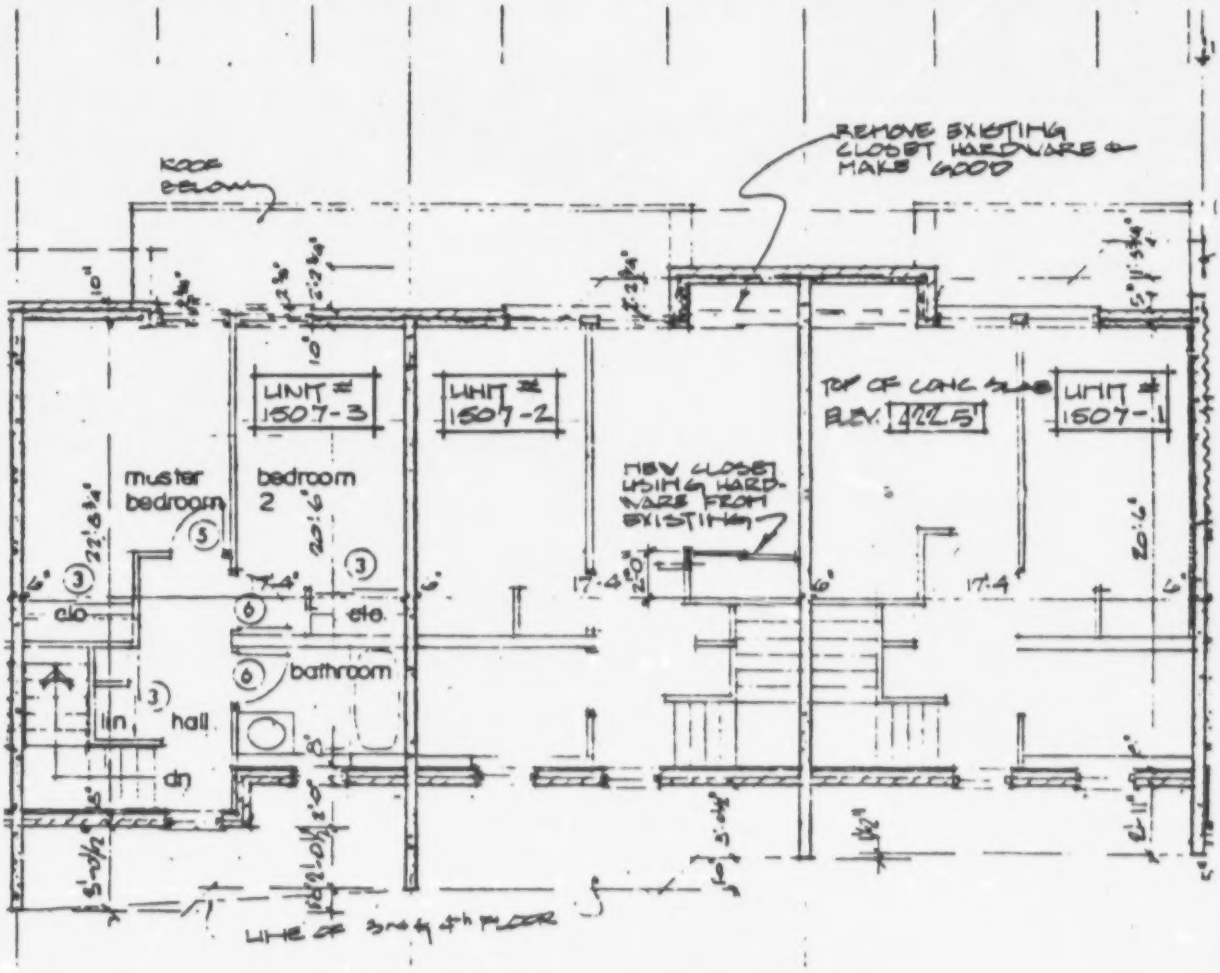


Photo 4.3 - Existing Floor Insulation, Exterior Closet

Exterior closet location showing existing insulation, (1½" polystyrene type I with CMHC material acceptance marking).



Hughes-Owens Geowel

Δ REVISED 5/11/82 CLOSET TO BE RELOCATED IN UNIT #1507-2 ONLY - DB	Project: PRIMROSE HOUSING — CLOSET RELOCATION	Title: UNITS 1507-1, 2, 3 BLOCK-1, 2ND FL.
	ALLEN-DRERUP-WHITE LTD. designers-builders and consultants energy conservation, solar heating (416) 863-1762 334 King St. E. Studio 505 Toronto, Ontario, M5A 1K8	Scale: 1/8"=1'-0" · Date: 13/4/82 · Ref. No.: 82-03 DD. · Drwg. No.: 1

	Project PRIMROSE CO-OPERATIVE -UNITS #1507 #2 & #507 #4, BLOCK #1	Title STEPPED SIDEWALL FLASHING
	ALLEN-DRERUP-WHITE LTD. designers-builders and consultants energy conservation, solar heating (416) 863-1762 334 King St E., Studio 505 Toronto, Ontario, M5A 1K8	Scale 1½"=1'-0" / Date 26/10/82 Ref. No. 82-05 / Drwg. No. 7-1

NEW PREPAINTED METAL FLASHING WITH ALL JOINTS CAULKED
LEAD FLASHING, FACE BRICK/SLAB JOINT
EXIST BRICK-CLAD EXTERIOR CLOSET SIDEWALL BELOW
ELEVATION
EXIST BALCONY RAILING
CAULK ALL JOINTS
CUT REGLET FOR NEW FLASHING
PRE-PAINTED METAL FLASHING
MECHANICALLY FASTEN CHANNEL CUP TO LOOK FLASHING ALONG BOTTOM BEVEL EDGE
EXIST BALCONY RAILINGS
EXIST BALCONY CONC. SLAB
CUT REGLET FOR NEW FLASHING ALONG TOP & SIDE OF FLASHING AS SHOWN (DOTTED LINE)
EXIST CONC. SLAB
SECTION

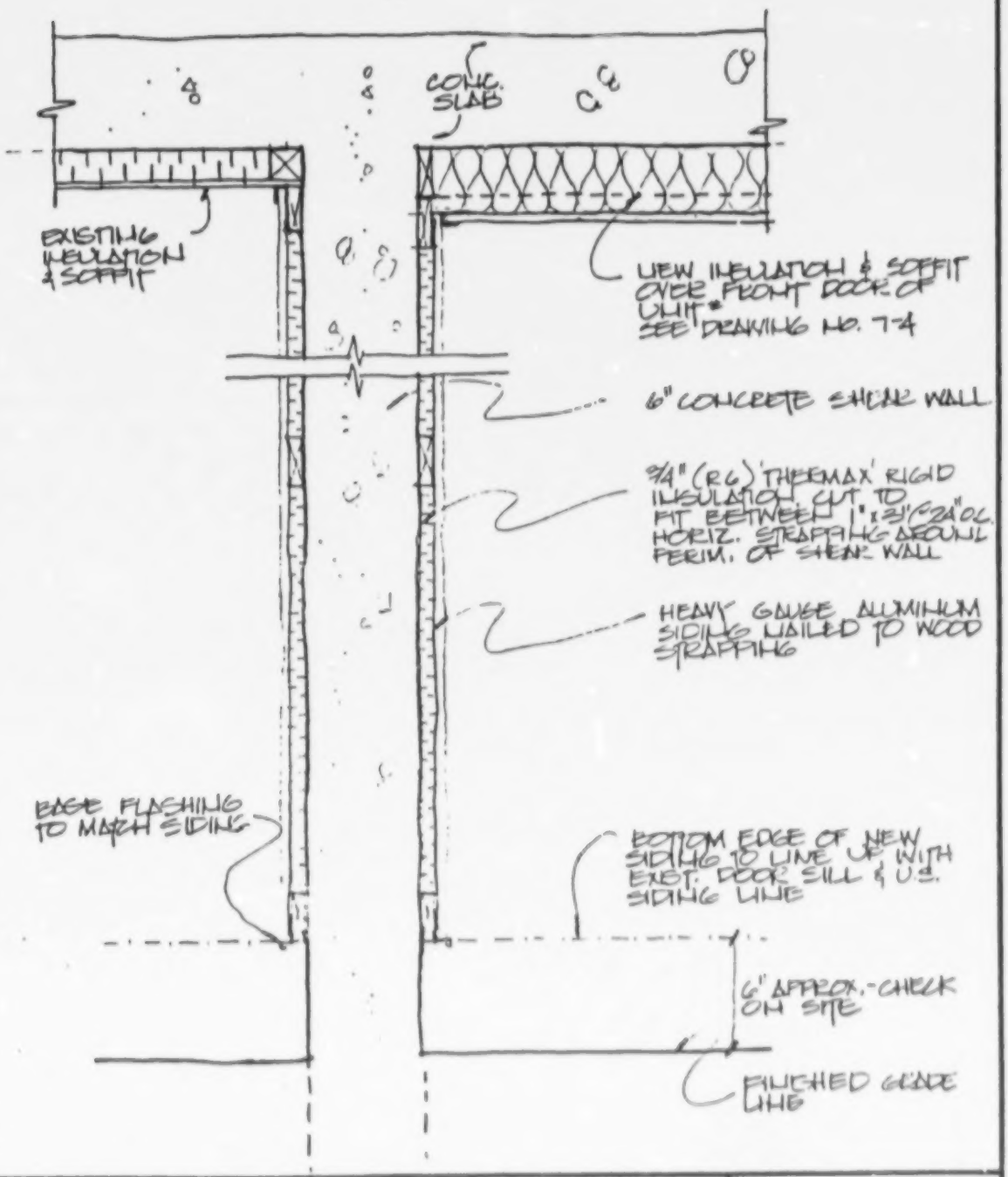
Project
PRIMROSE CO-OPERATIVE
UNITS #1501 #2 & #1501 #4, BLOCK #1

Title
BALCONY SLAB
LIVE FLASHING

ALLEN-DRERUP-WHITE LTD.
designers-builders and consultants
energy conservation, solar heating
(416) 863-1762
334 King St E., Studio 505
Toronto, Ontario, M5A 1K8

Scale	Date
1½"=1'-0"	26/10/82
Ref. No.	Drwg. No.
82-02	T-2

Hughes-Owens Geovel


CONC. SLAB
EXISTING INSULATION & SOFFIT
NEW INSULATION & SOFFIT OVER FRONT DOOR OF UNIT SEE DRAWING NO. 7-4
6" CONCRETE SHEAR WALL
3/4" (R6) 'THERMAX' RIGID INSULATION, CUT TO FIT BETWEEN 1"x3" C 24" O.C. HORIZ. STRAPPING AROUND PERIM. OF SHEAR WALL
HEAVY GAUGE ALUMINUM SIDING NAILED TO WOOD STRAPPING
EAGE FLASHING TO MATCH SIDING
BOTTOM EDGE OF NEW SIDING TO LINE UP WITH EXIST. DOOR SILL & U.S. SIDING LINE
6" APPROX. - CHECK ON SITE
FINISHED GRADE LINE

	Project PRIMROSE CO-OPERATIVE UNITS #1501 #1 & #1507 #2, BLOCK #1	Title SHEAR WALL INSUL. & SIDING
	ALLEN-DRERUP-WHITE LTD. designers-builders and consultants energy conservation, solar heating (416) 863-1762 334 King St. E., Studio 505 Toronto, Ontario, M5A 1K8	Scale: 1½"=1'-0" / Date: 26/10/82 Ref. No.: 82-05 / Drwg. No.: 7-4

Hughes-Owens Geovel

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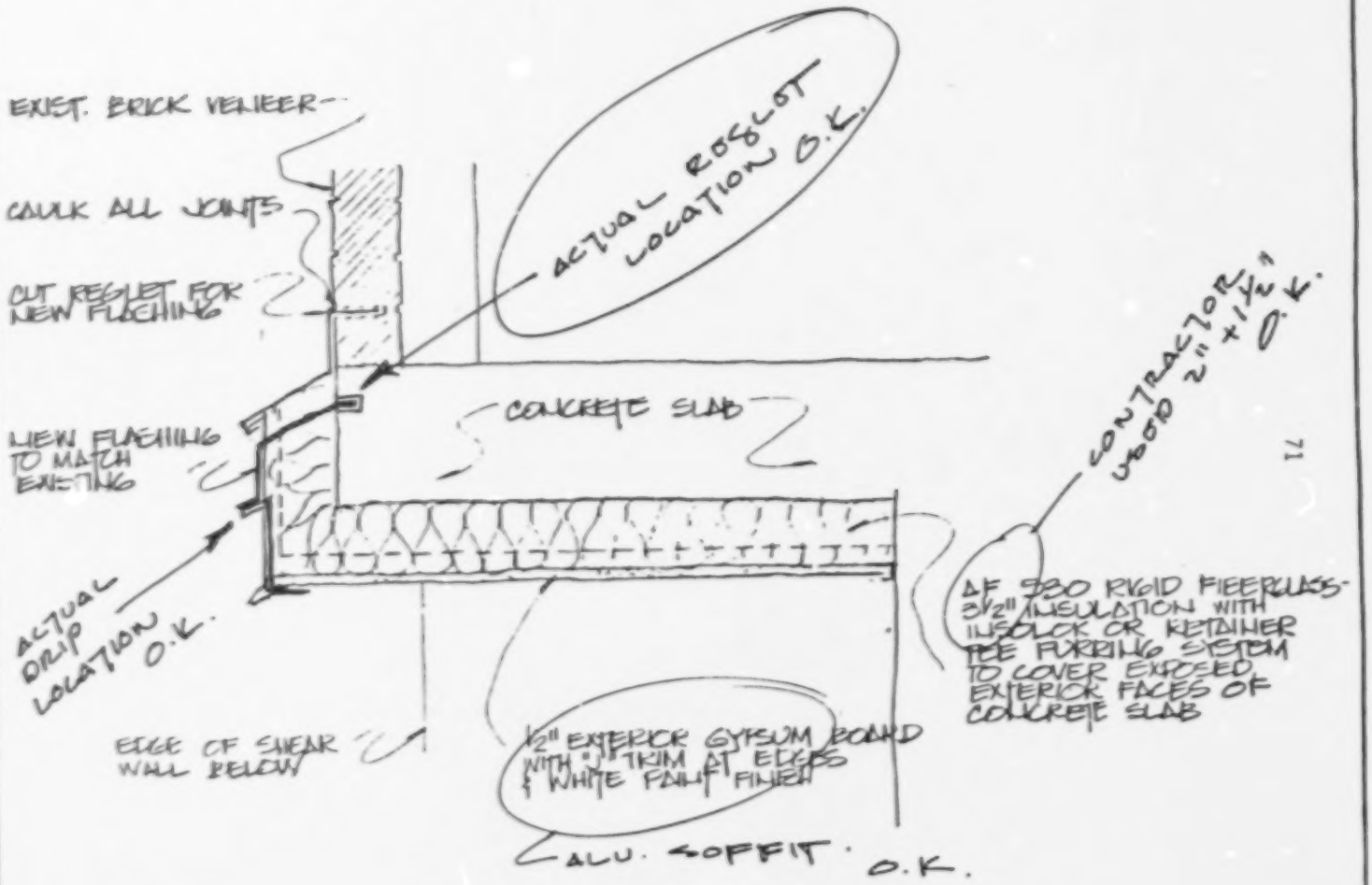

EXIST. BRICK VENEER
CAULK ALL JOINTS
CUT REGLET FOR NEW FLASHING
ACTUAL REGLET LOCATION O.K.
CONCRETE SLAB
NEW FLASHING TO MATCH EXISTING
CONTRACTOR USED 2" +1½" O.K.
ACTUAL DRIP LOCATION O.K.
Δ F 920 RIGID FIBERGLASS 3½" INSULATION WITH INSULOCK OR RETAINER TEE FURRING SYSTEM TO COVER EXPOSED EXTERIOR FACES OF CONCRETE SLAB
EDGE OF SHEAR WALL BELOW
½" EXTERIOR GYPSUM BOARD WITH "J" TRIM AT EDGES & WHITE FINISH
ALU. SOFFIT O.K.

71

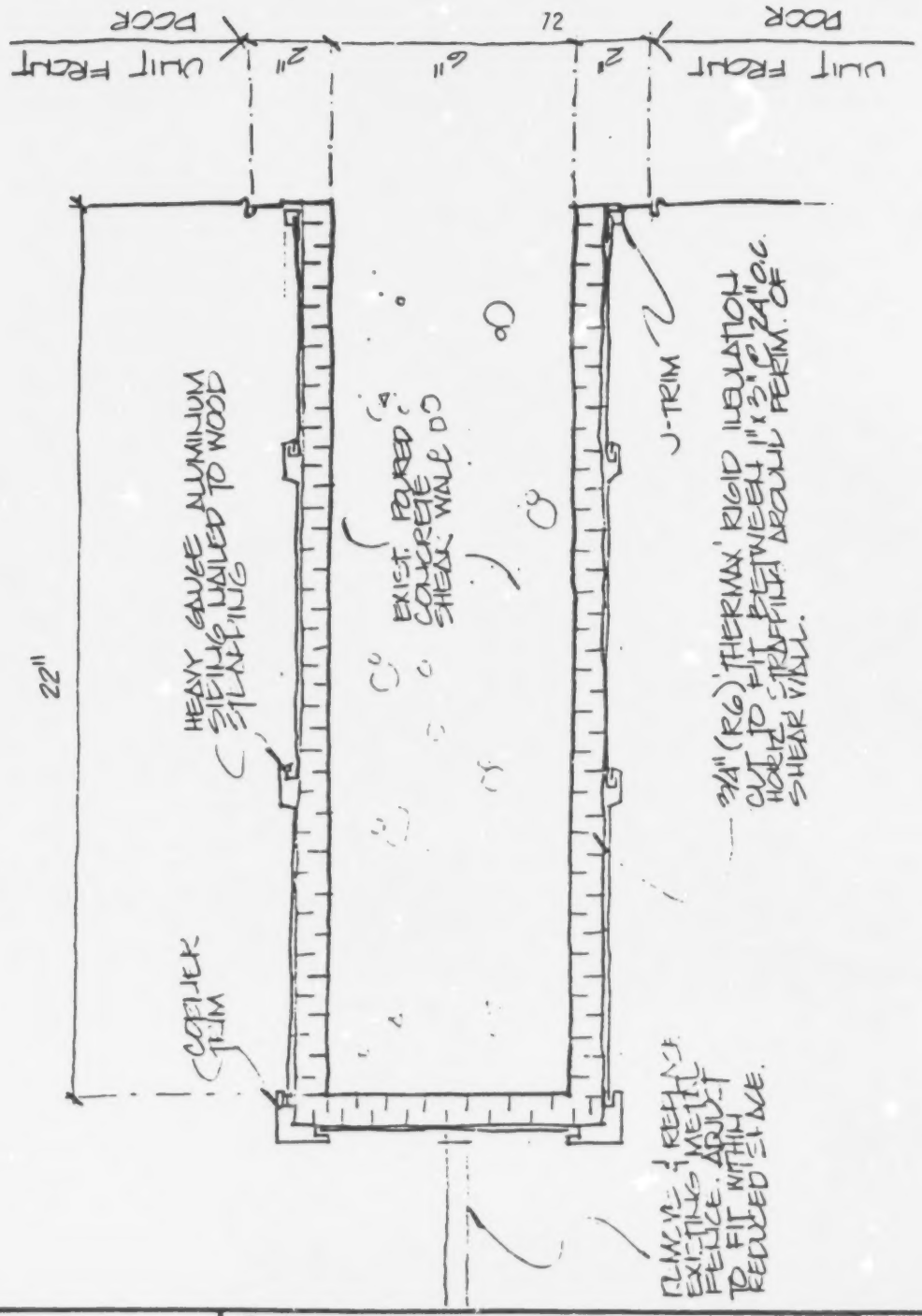
SITE INSTRUCTION GIVEN TO DAVE POANCOS, AL DESROCHERS 4/1/83

Project
PRIMROSE CO-OPERATIVE
UNITS #1507 #1 & #1507 #2, BLOCK #1

Title
NEW INSULATION @ SOFFIT

ALLEN-DRERUP-WHITE LTD
designers-builders and consultants
energy conservation, solar heating
334 King St E Suite 505
Toronto Ontario M5A 1K8
(416) 863-1762

Scale 1½"=1'-0"
Date 23/12/82
Ref. No. 82-23
Drwg. No. 1-3


UNIT FRONT
DOOR
11½"
11⅝"
72
11½"
UNIT FRONT
DOOR
22"
HEAVY GAUGE ALUMINUM SIDING W/ NAILED TO WOOD SHEATHING
EXIST. POURED CONCRETE SHEAR WALL
J-TRIM
¾" (R6) 'THERMAX' RIGID INSULATION CUT TO FIT BETWEEN 1"x3" @ 24" o.c. HORIZ. STRAPPING AROUND PERIM. OF SHEAR WALL.
COPPER FLASHING
REMOVE & REPLACE EXISTING METAL FENCE. ADJUST TO FIT WITHIN REQUIRED SETBACK.

	Project PRIMROSE CO-OPERATIVE UNITS #1507#1 & #1507#2, BLOCK #1	**Title** SHEAR WALL INSUL. & SIDING
	ALLEN-DRERUP-WHITE LTD. designers-builders and consultants energy conservation, solar heating (416) 863-1762 334 King St E., Studio 505 Toronto, Ontario, M5A 1K8	**Scale** 3"=1'-0"
		Date 26/10/82
		Ref. No. 82-05
		Drwg. No. 7-3

Duplication General

Photo 4.4 - Exterior View, Closet After Re-insulation

New slab-edge, soffit and shearwall insulation system in place at exterior closet location.

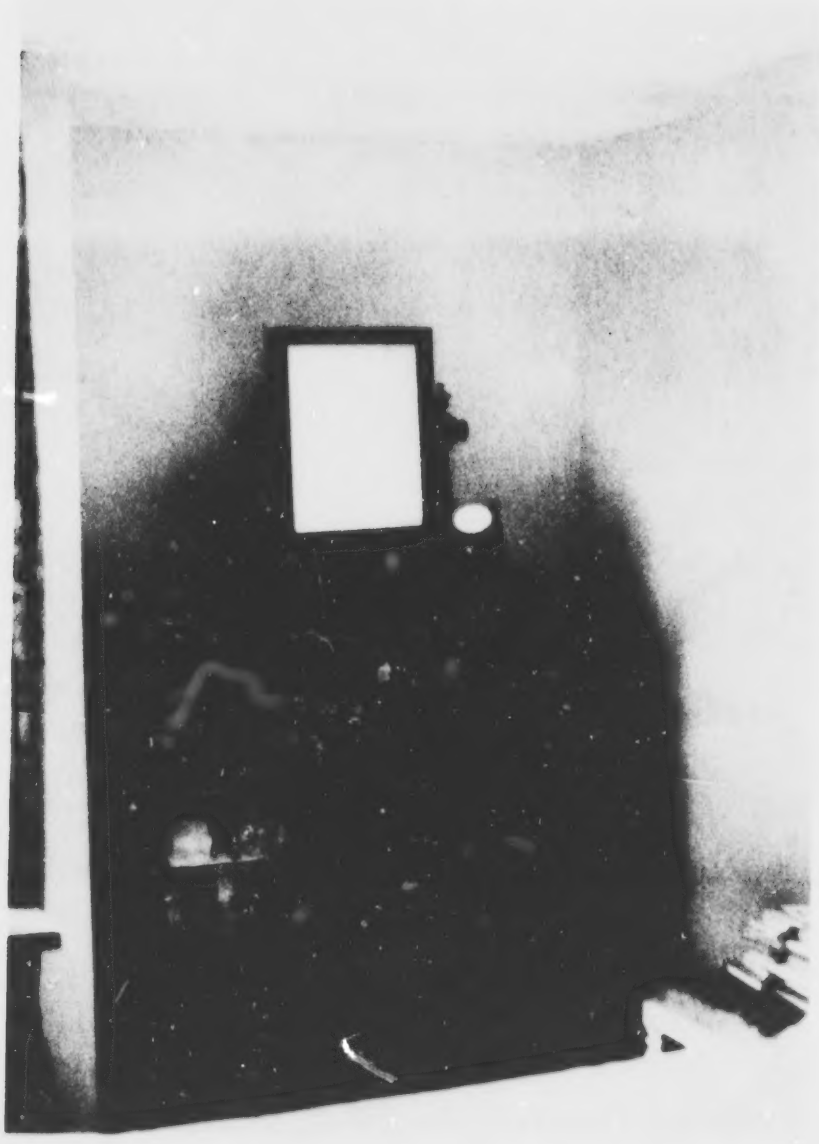


Photo 4.5 - Interior View,
Closet Removed

Exterior closet location -
after relocation of closet.

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4.3.2 Slab Temperatures (Closets)

Surface temperatures of the closet floor (overhang) areas were measured on January 9, 1984 (outdoor temperature -7.0°C) and January 24, 1984 (outdoor temperature (2.5°C). The relevant data is listed in Table 4.1. Typical minimum measured surface temperatures near the exterior wall are given. The surface temperatures were recalculated assuming the design conditions of 20°C, 40% R.H. indoors, 20°C outdoors. Note that the dew point is 7°C.

UNIT NO.	INSULATION STATUS	CLOSET STATUS	MEASURED			AT DESIGN CONDITIONS**
			OUTDOOR TEMP(°C)	INDOOR TEMP(°C)	SURFACE TEMP(°C)	PREDICTED MINIMUM SURFACE TEMP.
1507 #1	Retrofitted	-not removed -floor covered to depth of 18"	2.5	24.2	11.5	1.0
1507 #2	Retrofitted	Removed	-7.0 2.5	19.0 21.2	8.5 12.5	3.8 5.4
1507 #4	Original	-not removed -floor not covered	-7.0 2.5	20.0* 21.3	8.5 11.0	5.0 2.7
1507 #7	Original	-removed -space occupied by desk	2.5	23.7	12.0	2.1

*Assumed
**20°C, 40% R.H. indoors, -20°C outdoors

Table 4.1 SUMMARY OF CLOSET FLOOR TEMPERATURES

In addition, a conduction model taking into account thermal bridging of the brick veneer was developed and used to calculate floor surface temperatures near the exterior wall. The purpose is to explain the poorer than expected performance of the retrofit insulation applied to the slab overhang.

4.3.2 Slab Temperature (cont'd)

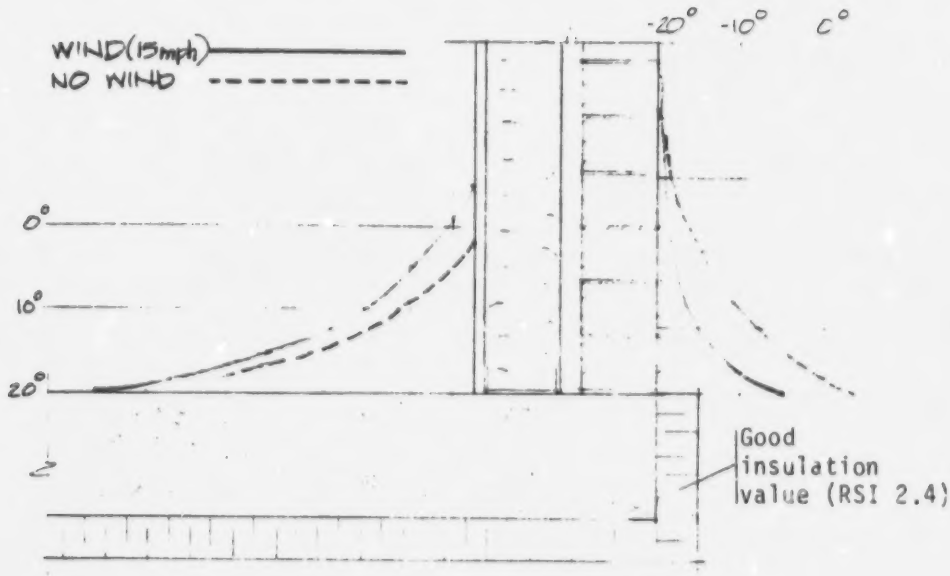

Figure 4.1 Calculated Surface Temperatures Interior and Exterior Surfaces at Design Condition

If we consider a slab edge condition as in Figure 4.1 and assume that heat loss through insulated portions, being well insulated, is negligible with respect to the thermal bridge, the equation for a two dimensional heat flow through a fin apply.

If T_x = temperature of surface at distance x (^oC)

T_w = temperature of surface at wall junction (^oC)

T_i = temperature of indoor air (^oC)

T_o = temperature of outdoor air (^oC)

h_i = skin heat loss coefficient indoors ($w/^oC\text{-}m^2$)

h_o = skin heat loss coefficient outdoors ($w/^oC\text{-}m^2$)

k = masonry conductivity ($w/^oC\text{-}m$)

t_i = thickness of interior slab (m)

t_o = thickness of exterior brick (m)

$$T_w = \frac{T_i\sqrt{h_i k t_i} + T_o\sqrt{h_o k t_o}}{\sqrt{h_i k t_i} + \sqrt{h_o k t_o}}$$

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4.3.2 Slab Temperature (cont'd)

$$\text{and } T_i = T_i + (T_w - T_i) \cdot \exp\left(\frac{-h_i}{kt_i}\right)$$

$$T_y = T_o + (T_w - T_o) \cdot \exp\left(\frac{-h_o}{kt_o}\right)$$

The results of analysis of temperature profiles for both calm air and windy conditions at -20°C outdoor temperature and 20°C indoors are shown in Figure 4.1. It is evident from this analysis that average temperatures near the inside of the wall are approaching the freezing point. This correlates well with predicted values derived from measured temperatures in Table 4.1. It is apparent that merely insulating slab edges on which brick veneer bears does not significantly alter indoor surface temperatures. If the conductivity on the inside (h_i) is decreased, as with carpets or boxes, the indoor surface temperatures decrease exascerbating condensation problems.

The following conclusions can be drawn from the above measurements and calculations (see Table 4.1):

1. By removing the closet and improving the insulation there was an increase in minimum surface temperature of 1.5°C.

2. The use of the closet space by residents can have a a significant effect on surface temperature.

3. Only modest improvements can be made by insulating slab edges and increasing insulation beneath overhang if thermal bridging through brick veneer remains.

4. All "measured" values at the design conditions are below the dew point, i.e. condensation would occur.

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4.3.3 Flashing

On January 9, 1984 1" of wet snow was observed melting from all the balconies. Very pronounced water stains were created on the exterior brickwork.

From the observations of block #2 it was evident that the flashing retrofit of balcony level did not perform as expected in directing water away from the wall (see Photo 4.3). It seemed quite clear that there was no reduction in water staining. It is also interesting that a significant amount of water bypasses the drip groove, on the underside of the concrete slab. It is possible that water can run on the underside of the slab towards the wall and be channeled along the top of the side wall.

The flashing at the bottom of the wall spills water directly onto the roof and while the pattern was not obvious, it is expected that it is performing properly.

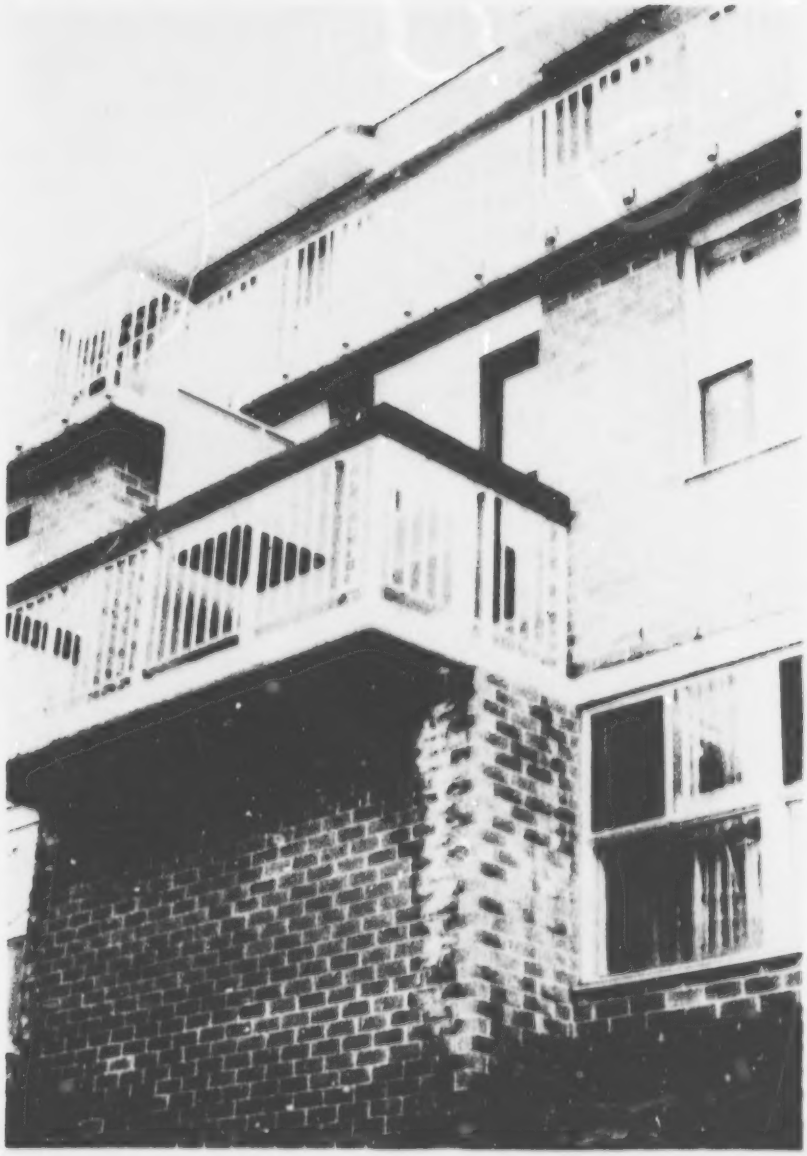

Photo 4.6 - Exterior View, Closet
Prior to New Flashing

Exterior closet -
water run-off pattern prior to
installation of flashing.

Photo 4.7 - Exterior View, Closet with New Flashing

Water run-off pattern - not appreciably changed after new flashing.

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4.4 Slab Heating

Two locations in the buildings were considered for slab heating being a) Location II - b) - overhang at shearwall, and b) Location III - c) - closet overhang. Preliminary analysis showed that installation costs of $500.00 per location could be expected with maximum additional heating costs of $12.00/year. This was then compared to the alternative of adding insulation for each location.

Location a) insulation cost was estimated at $1,300.00 and savings in heating of $20.00/year. Heating was chosen at this location as the additional cost of insulating was large ($800.00) in relation to the expected benefit ($32.00/year).

Location b) insulation cost was estimated at $500.00 and so was selected over heating.

The most severe thermal bridge location measured was selected. This area had a predicted surface temperature of -10°C at the outdoor design extreme.

The heater chosen was a 16" wide x 4'-5" length of "flex-heat" carbon-filament heating strip rated at 16 watts/ft. of length @ 208V - 1 phase, giving a total capacity of 71 watts. The heater was adhered directly to the underside of the concrete slab and a new soffit with fiberglass insulation was used to cover. The heater was controlled by a wall-mounted remote bulb thermostat with the bulb installed in a hole drilled into the slab. (See Dwg. 16-2.)

The operation of the heater was monitored by an elapsed-time meter and the thermostat set at 10°C. Slab temperatures (interior) were recorded between 9°C and 14°C, depending on the occasion.

During the period February 21, 1983 to March 21, 1983, 276.2 hours of operation were recorded. Extrapolated to one year's operation (by degree-day method), 161 kWh can be expected to be consumed. Based on current rates this represents $6.00 in additional heating expense. Further calculation shows that even if the heater were to run continuously for 6 months (without control) the power consumption would amount to $11.22.

No wetness or frosting was observed throughout the heating season and this installation is considered to be successful.

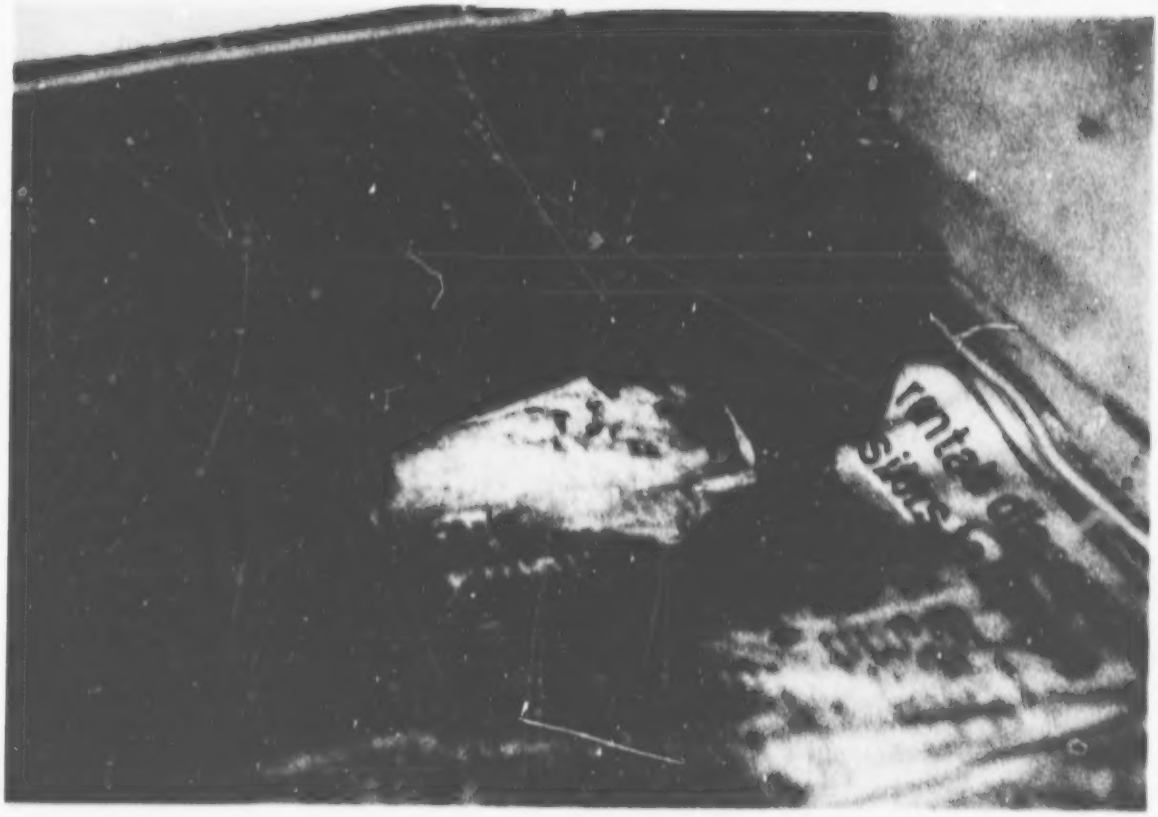
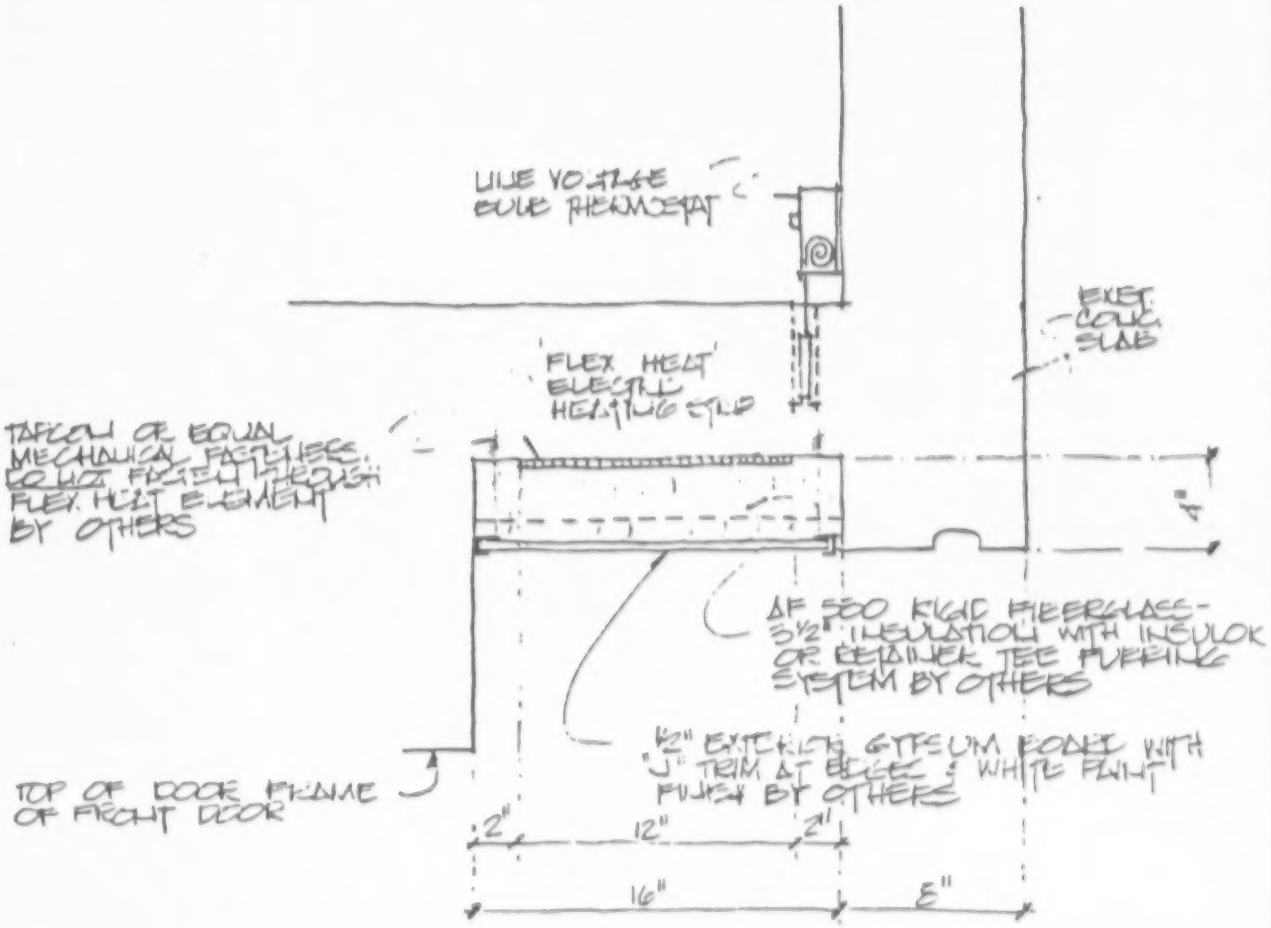


Photo 4.8 - Location Type II-c,
Interior View

Accumulation of frost at end of carpet (prior to slab heater installation).


LINE VOLTAGE
EDGE THERMOSTAT
EXIST. CONC. SLAB
FLEX. HEAT ELECTRIC HEATING CABLE
TAPCON OR EQUAL MECHANICAL FASTENER. DO NOT PENETRATE THROUGH FLEX. HEAT ELEMENT BY OTHERS
AF 500 RIGID FIBERGLASS-5½" INSULATION WITH INSULOK OR EQUIVALENT FURRING SYSTEM BY OTHERS
½" EXTERIOR GYPSUM BOARD WITH "J" TRIM AT EDGES & WHITE PAINT FINISH BY OTHERS
TOP OF DOOR FRAME OF FREIGHT DOOR
2"
12"
2"
16"
8"

	Project PRINCESS HOUSING UNIT 1500 #1, BLOCK #2	Title HEATING STRIP & SOFFIT INSTALLATION
	ALLEN-DRERUP-WHITE LTD. designers-builders and consultants energy conservation, solar heating (416) 863-1762 334 King St E., Studio 505 Toronto, Ontario, M5A 1K8	Scale 1½"=1'-0" / Date 22/6/8 Ref. No. 82-03 / Drwg. No. 16-2

Hughes-Owens

Interior view of slab heater installation showing control and duration timer. (Location II-c)

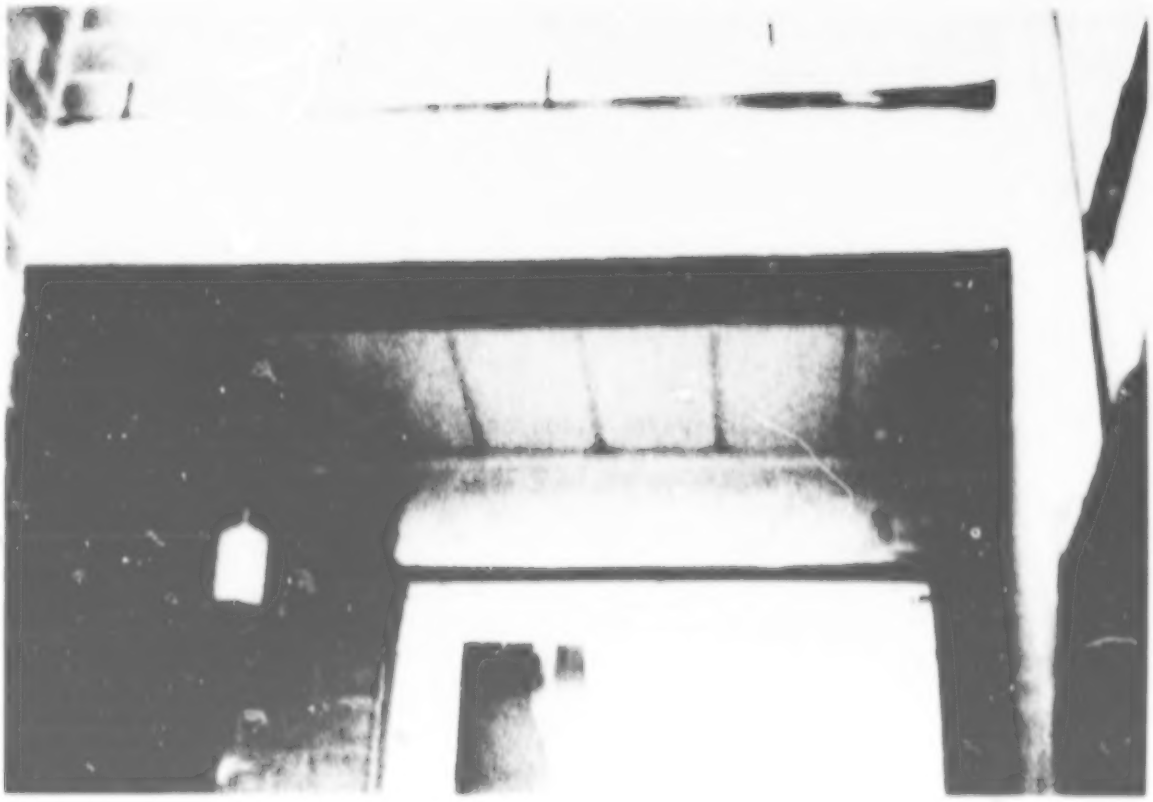


Photo 4.10 -

Exterior view, new soffit installed
over slab heater.
(Location type II-c)

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4.5 Air Sealing and Ventilation

4.5.1 Description

From Section 4.4 the mechanisms identified which contribute to high humidity levels and resulting condensation can be summarized as follows:

1) Low levels of air-change resulting from airtightness and configuration of the envelope

2) Stack effect movement of air from lower units to upper units

3) Absence of ventilation of a continuous nature.

In order to address the mechanisms cited above, and in view of the overall budget available, the following program was carried out:

1) To airseal all air paths from lower units to upper units.

2) To install switches on lower unit basement fans to allow their continuous operation and to install speed controls on upper unit fans to allow their continuous operation.

In order to ensure a valid trial these measures were put in place in all units of block 1.

4.5.2 Air Sealing

Monitoring consisted of the placement of hygrothermograph recorders as in the previous year.

Analysis of the data gathered during 1983 does not show any discernible difference from the previous year during normal operation (see Figure 4.2). This leads to the possibility that the passageways from lower to upper units have not been completely closed, or that this is not the dominant mechanism. No significant alleviation of symptoms was produced.

In order to verify the conclusions made above it would be necessary to repeat some of the tracer gas tests performed in the early part of the study.

Photo 4.11

Existing basement ventilation fan with new switch for independent operation.

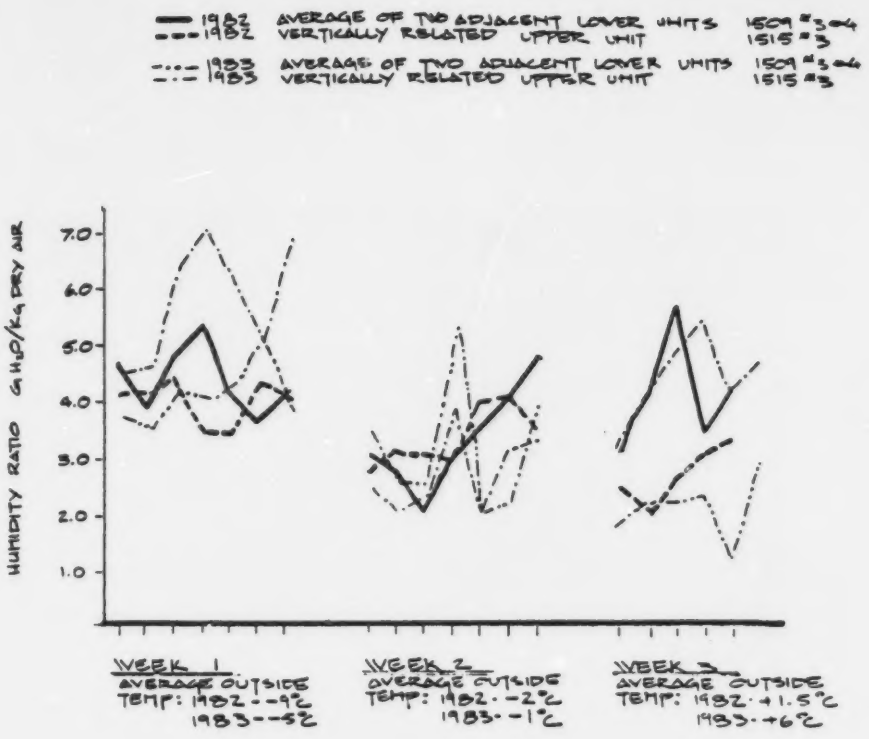

Figure 4.2 Comparison of Humidity Data, 1982 vs. 1983 Vertically Related Upper and Lower Units

4.5.3 Ventilation

Questionnaire results showed that townhouse residents used their basement fans continuously and some improvement in conditions resulted. (Hygrothermograph results do not support this observation.)

Questionnaire results from apartments were variable, in some cases a marginal effect was noted, in another no effect whatsoever was noted and in another the resident did not operate the fan as instructed.

A further trial that was made after a visit on March 21, 1983 showed that three units were experiencing continuing water accumulation but with speed controls adjusted to the off position. A fourth unit showed no evidence of water accumulation and the speed control was in the 1/2 speed position.

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4.5.3 Ventilation (cont'd)

The trial consisted of three sequential weeks in which hygrothermograph records were taken in 4 sample upper units (of a a group of 7 in block 2) and the hallway as follows:

1st week: All fans turned off and speed controls sealed in the 'off' position.

2nd week: All fans turned full on and speed controls sealed in the 'on' position.

3rd week: All fans returned to 'normal' operation. Speed controls were left in the 1/4 rotation position.

The results were positive and fairly direct, showing a reduction of 1 g/kg in air moisture content attributable to the use of the fans, in all but one unit monitored. The results are shown in Figure 4.3 and 4.4.

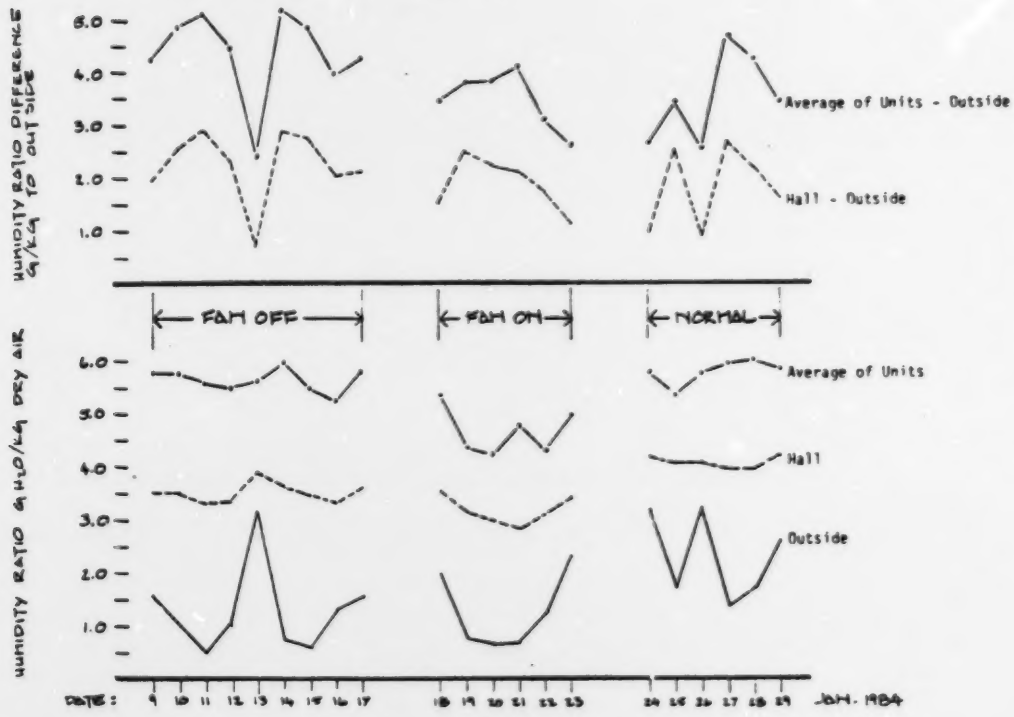

Figure 4.3 - Humidity Ratios During Trial of Block 2 Upper Unit Ventilation Fans

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4.5.3 Ventilation (cont'd)

Confirming observations were made from the data taken from the hallway, where the air temperature fell an average of $1^{0}C$ during the week when fans were operated on high speed, indicating an increase in heat load due to the entry of additional outside air. It should be noted that it is the intent of the air-sealing and ventilation measures put in place, to promote air entry from the hallway, rather than lower units.

It is likely that a longer period of fan operation in this mode would have produced further reduction in moisture content due to storage characteristics of the building materials present.

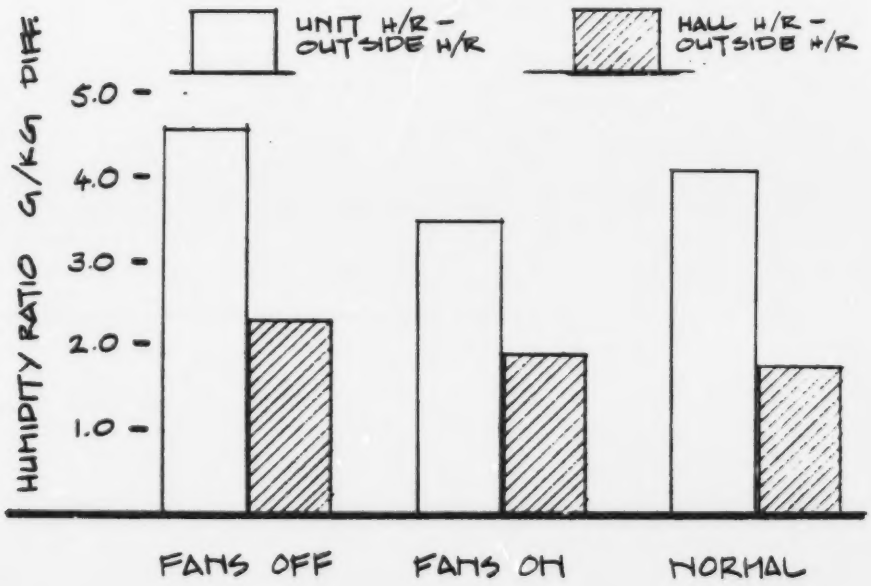

Figure 4.4 - One week average* of difference between between indoor humidity ratio and outside humidity ratio

*Adjusted average by removing highest and lowest humidity reading from each data set.

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4.5.4 Ventilation Analysis

Results of the ventilation trial showed that a reduction of the average indoor/outdoor humidity ratio difference by at least 1.0 g/kg was possible using continuous fan operation in upper units. The fans are of approximately 50 l/s capacity (measured).

A variety of assumptions may be made concerning the translation of this effect to a given change in "net" ventilation. The humidity ratio difference may be translated directly into a "net" ventilation rate and increase in same, if the moisture generation rate were to remain constant.

It is more likely that a certain portion of the net moisture removed originated from "hidden moisture"[12] and that the "hidden moisture" generation rate increases with any lowering of the interior vapour pressure.

A series of calculations of net ventilation rates were made assuming:

- a constant occupant moisture generation rate of 3.0 kg/day/person[5] (assume one person per unit for this calculation)
- 2 cases of "hidden moisture" generation being:

Case 1) No hidden moisture effect. The initial net ventilation rate (week 1, fans off) and the increased net ventilation rate (week 2, fans on) are calculated from the difference of indoor-outdoor air moisture content and the constant occupant moisture load (3.0 kg/day).

Case 2) Doubling of hidden moisture effect. Calculation of net ventilation rate is based on the constant difference of indoor-outdoor air moisture content for the two test weeks (fan off and fan on) and the following moisture loading

Week 1 (fan off) - constant occupant load plus 10% hidden moisture

Week 2 (fan on) - constant occupant load plus 20% hidden moisture to correpond to increased release of moisture due to the lowering of room-air moisture levels.

The results of these calculations were compared for sensitivity to the hidden moisture component with the following result:

	Off	On	% Diff
Case 1	6.27 l/s	8.23 l/s	24%
Case 2	6.89 l/s	9.88 l/s	30%

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4.5.4 Ventilation Analysis (cont'd)

The use of the fans appears to have resulted in an increase from 24 to 30% or more in net air change. If moisture generation rates are assumed to lie between 3.0 and 6.0 kg/day[5] for an occupancy of one to two persons, the initial net ventilation rate for upper units can be estimated at from 6.3 l/s to 14.6 l/s.

A second analysis procedure was used as follows:

1) Assuming that the 'fan off' net (natural) ventilation rate of the upper unit is 10 l/s or 36 m^3/hr
2) The 'fan off' net ventilation of the two lower vertically related units combined is 111 m^3/hr, as shown by the tracer gas tests.
3) Considering that the upper unit and lower two units continue to act as a unit, the total 'fan off' net ventilation rate of 147 m^3/hr, applied to the total volume of 666 m^3, yields a net 'fan off' air change rate of .22 for the system.
4) In the 'fan on' mode 50 l/s (180 m^3/hr) of exhaust air movement is added to the system.
5) By using the correlation developed by Shaw[11], the influence of 180 m^3/hr of exhaust only ventilation (.27 ach) yields an increase in net ventilation from .22 ach to approximately .30 to .33 ach, or an increase of from 26 to 33% which confirms the ventilation analysis based on moisture level changes.

On the other hand, if applied to the upper unit in isolation this theory does not correlate to the analysis of ventilation rates, based on moisture level changes.

The following conclusions may be drawn from the above analysis:

a) The air-sealing work was apparently not effective in isolating the upper unit, and the upper and lower units continue to act as a system, from the ventilation point of view. Tracer gas testing would be required to confirm this.

b) Addition of continuous exhaust of 50 l/s would be required to produce a 'system' air change rate in the range of 0.3 ach considered to be a minimum for humidity control purposes.

c) Net 'natural' air changes rates of between 6 and 14 l/s (0.18 and 0.42 ach) exist in the upper unit, which may be increased to between 8 and 18 l/s (0.24 and 0.54 ach) by addition of 50 l/s of continuous exhaust.

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4.5.4 Ventilation Analysis (cont'd)

d) If the upper and lower units continue to act as a system the air change rate of the lower units may be increased from .2 ach (15 l/s/unit) to .3 ach (23 l/s) as a by-product of the 50 l/s exhaust fan.

Unless further investigation is made using tracer gas to establish the effectiveness of the air-sealing work, ventilation system modifications would have to address either the positive supply of fresh air to upper units, or the positive exhaust of air from both upper and lower units. Use of a balanced ventilation system (equal supply and exhaust) could also be used and would be strictly additive to the existing natural ventilation.

4.5.5 Ventilation Control

The control method used for the trials was not successful.

Occupants did not operate their fans in a consistent manner and could not relate any change in humidity indicators to use of the fan speed control.

In order to be effective the fan controls would have to be removed from the occupants' control, the best method being a continuous mid-speed level combined with a wall-mounted dehumidistat control which would provide high speed operation during periods of high humidity.

Humidity-control alone of the existing fans would probably not be sufficient as the fans are sufficiently noisy to cause the occupants to not properly adjust the control.

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4.5.6 Moisture Levels

The initial presumption of the analysis of thermal bridges was control of interior moisture levels to 40% R.H at 20°C This would allow a minimum surface temperature of 7.0°C without condensation and corresponds to the surface temperature of common double glazing at -20°C outside and 20°C inside. Any thermal bridge under the above design conditions that exhibits interior surface temperatures of more than 7°C can be considered to be non-problematic. This corresponds to an air moisture content of 5.75 grams H_2O/kilogram of dry air.

Monitored moisture levels in upper units over the three years averaged approximately 6.0 G/KG, or slightly higher than the allowable upper limit, during correspondingly cold weather (less than 0°C). However, a number of thermal bridges would have surface temperatures at the design conditions lower than 7°C.

Results of trial ventilation measures show that a reduction to 5.0 G/KG at least, and possibly 4.0 G/KG is possible in upper units with the ventilation changes considered. Lowering interior moisture to these levels would have a positive result concerning thermal bridges; that is,at the lower moisture level a number of previously problematic thermal bridges would no longer produce condensation. (See Figure 4.5 for Chart of Thermal Bridges vs. Moisture Level and Temperature)

Control to 4.0 G/KG (28% R.H. @ 20°C) vs. 5.75 G/KG would result in the reduction of minimum allowable surface temperature to +1°C i.e. the dewpoint for a moisture level of 4.0 g/kg. This condition reduces the number of "problematic" thermal bridges identified from 12 to 7.

During the monitoring it was noted that in an effort to conserve energy, many occupants reduced the space temperature below 20°C. Some units were operated as low as 14° and temperatures maintained below 18°C were not infrequent.

At 14°C, the surface temperature of an 'acceptable' +1°C @ 20°C bridge would be reduced to -2°C and would require a lowering of interior moisture content to 3.25 G/KG in order to avoid condensation. This in turn would require a 33% increase in ventilation rate if the moisture generation rate is assumed to remain constant.

It follows, therefore, that the minimum acceptable thermal bridge condition is not only a function of the expected interior moisture level but also the temperature at which the unit is maintained.

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4.5.6 Moisture Levels (cont'd)

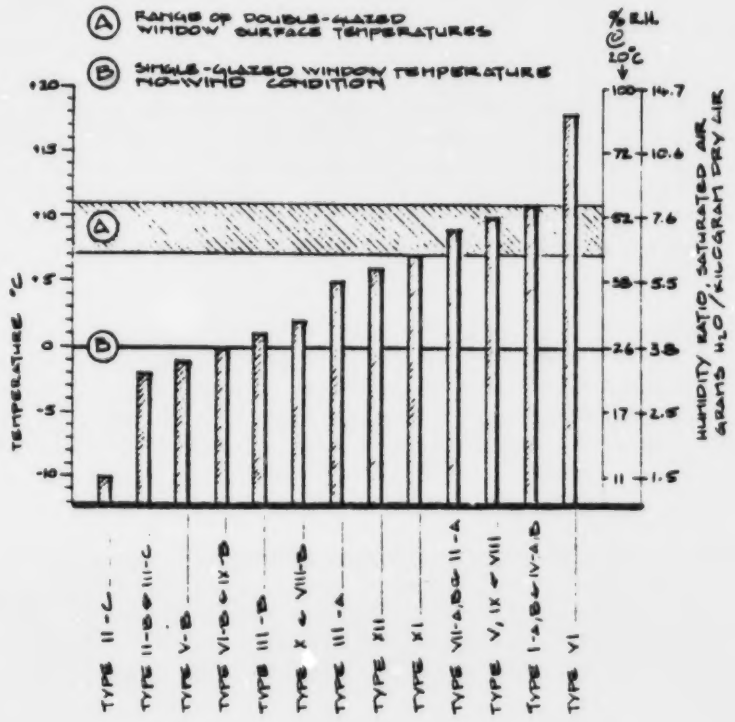

Figure 4.5 - Chart of Predicted Thermal Bridge Surface Temperatures at "Design" Conditions of 20°C Indoor & - 20°C Outdoor Temperatures, Glass Temperatures at 20°C and -20°C. See 3.1.2 for for Derivation of Predicted Temperatures and Description of Thermal Bridges

If the existing ventilation means are to be used, the following conclusions can be drawn regarding the limits of the probable results:

1) If space temperatures are not controlled to 19-20°C, thermal bridges showing minimum temperatures of +5°C and lower must be treated.*

2) If space temperatures are controlled to 19-20°C, thermal bridges showing minimum temperatures of +2°C would be acceptable.

*Assumes control of moisture level to 4.0 g/kg

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SECTION 5.0 CONCLUSIONS

This investigation restricts itself to the problem of moisture damage at floors, ceilings, walls and around door and window frames and those mechanisms which contribute to these problems through high humidity and condensation. During the investigation several instances of leakage from exterior water sources were noted and the mechanisms leading to these problems have not been investigated unless in relation to humidity or condensation.

Although the problems with the buildings are manifested in varied forms they may be broken down into several sites of action and contributory mechanisms. These may be categorized in terms of workmanship, design (specific to this building), lifestyle (relating to the occupants' use of the space) or technology (general to construction practices presently in use).

Specific manifestations and mechanisms are discussed individually in the following text, organized under the appropriate category. Conclusions are drawn based on the results of the testing and trials carried out, the specific results of which are described in Sections 3 and 4.

5.1 Workmanship

Problems included here arise out of failure by the builder and his forces to carry out the intent of the designers.

5.1.1 Water Leakage

Several instances of water leakage into the building have been noted, and are due to faulty construction. The leaks are both above and below grade.

Above grade leaks allow water to enter during rain or snowmelt and below grade leaks permit water entry on a more continuous basis, whenever sufficient water is present in the soil.

In a building which has a limited capacity to carry away moisture due to tightness of construction and reduced ventilation the introduction of additional water via leakage will result in higher humidity levels than would otherwise be the case. Even intermittent leaks can affect humidity levels over long periods due to soaking of interior building materials. Constant wetting of building materials from ground-water entry can add significant amounts of moisture to interior air.

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5.1.1 Water Leakage (cont'd)

The amount and rate of such moisture addition is not capable of being quantified, but can be sufficiently large to result in uncontrollable high humidity or require ventilation well above that normally required for humidity control and control of indoor contaminants.

Control of outside moisture and proper below grade dampproofing is an essential requirement of performance for a building with low-air leakage and ventilation rates.

5.1.2 Firestopping

Firestopping was apparently omitted at between-floor pipe penetrations and is a contributor to the stack effect movement of air in the building. This is discussed in 5.4.2.

5.1.3 Lack of Air-Sealing

As described in 3.5.17, a requirement of the specification calling for caulking of wall/floor, wall/ceiling and window surround joints was not performed.

While this may have serious implications for the longevity of the exterior wall, and certainly produces pronounced effloresence round windows on the lee-ward side, this ommission does not appear to contribute to interior surface moisture deterioration. Moreoever, as shown by fan-depressurization tests,these sites represent a major route of air entry and exit, contributing to the natural air change rate of the building.

It is probable that if these sites had been sealed as called for, the existing problems would have been more serious.

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5.2 Design

Problems included in this section arise out of the design of the building, that is, details, configurations and material specifications which are specific to these buildings.

5.2.1 Thermal Bridges

Thermal bridges, consisting of concrete structural elements which extend through the building skin exist throughout these buildings. Condensation, damage, and sometimes frost buildup was observed on interior surfaces of many of these thermal bridges. Other thermal bridges, however, did not exhibit any evidence of condensation.

Testing was carried out in order to characterize the various thermal bridge configurations so that conclusions might be drawn as to their interaction with the building's problems. The test method, results of testing and predictions of performance under various conditions are presented in Section 3.0 TESTING and summarized in Table 4.5

In drawing conclusions from the results of testing it has been assumed that the practical upper limit of interior relative humidity in the dwelling units is the R.H. level at which condensation will begin to form on interior window glass surfaces. An interior R.H. upper limit of 40% was chosen based on reference[1] and an exterior design temperature of $-20^{o}C$[2]. This provides a criteria upon which to judge a given thermal bridge, that is; a thermal bridge exhibiting condensation at interior R.H. levels below 40% R.H. (@ $-20^{o}C$ outside) is considered to be problematic, and a bridge exhibiting no condensation at 40% R.H. interior (@ $-20^{o}C$ outside) is considered to be acceptable.

5.2.1 Thermal Bridges (cont'd)

Given the above criteria and based on the results of testing it is clear that most of the common thermal bridges (i.e. exposed slab edges) are not problematic. Where these otherwise acceptable configurations meet a second element such as an endwall or shearwall which is substantially exposed to the exterior, the resulting condition is unacceptable. The effect of intersecting, exposed shearwalls on slab temperature can be clearly seen in the temperature map of a single bedroom apartment shown in Figure 5.1.

A further influential factor is the occupant's furnishings of the space, that is their use or non-use of floor coverings. If an occupant installs a carpet or other insulative floor covering, the flow of heat into the structural slab is somewhat reduced, having the effect of lowering the interior slab surface temperature. Unfortunately, it is a normal occupant reaction to lay a carpet on a floor area which is cold and uncomfortable. Fortunately, as far as can be ascertained from testing, the use of carpet does not sufficiently aggravate the less serious thermal bridge conditions so as to render them problematic. It does appear, however, that the use of carpet in a problematic bridge configuration will produce more pronounced damage and significantly lengthen the periods during which condensation can be expected.

The design of spaces can influence the severity of a given thermal bridge. The installation of a closet or cabinet which separates the bridge location from the heated space will have the effect of lowering surrounding air temperature and promoting condensation. In addition such an enclosure is naturally used by occupants as storage space. Articles placed against the bridge location insulate it from the general heated space and produce lower surface temperatures.

Figure 5.1

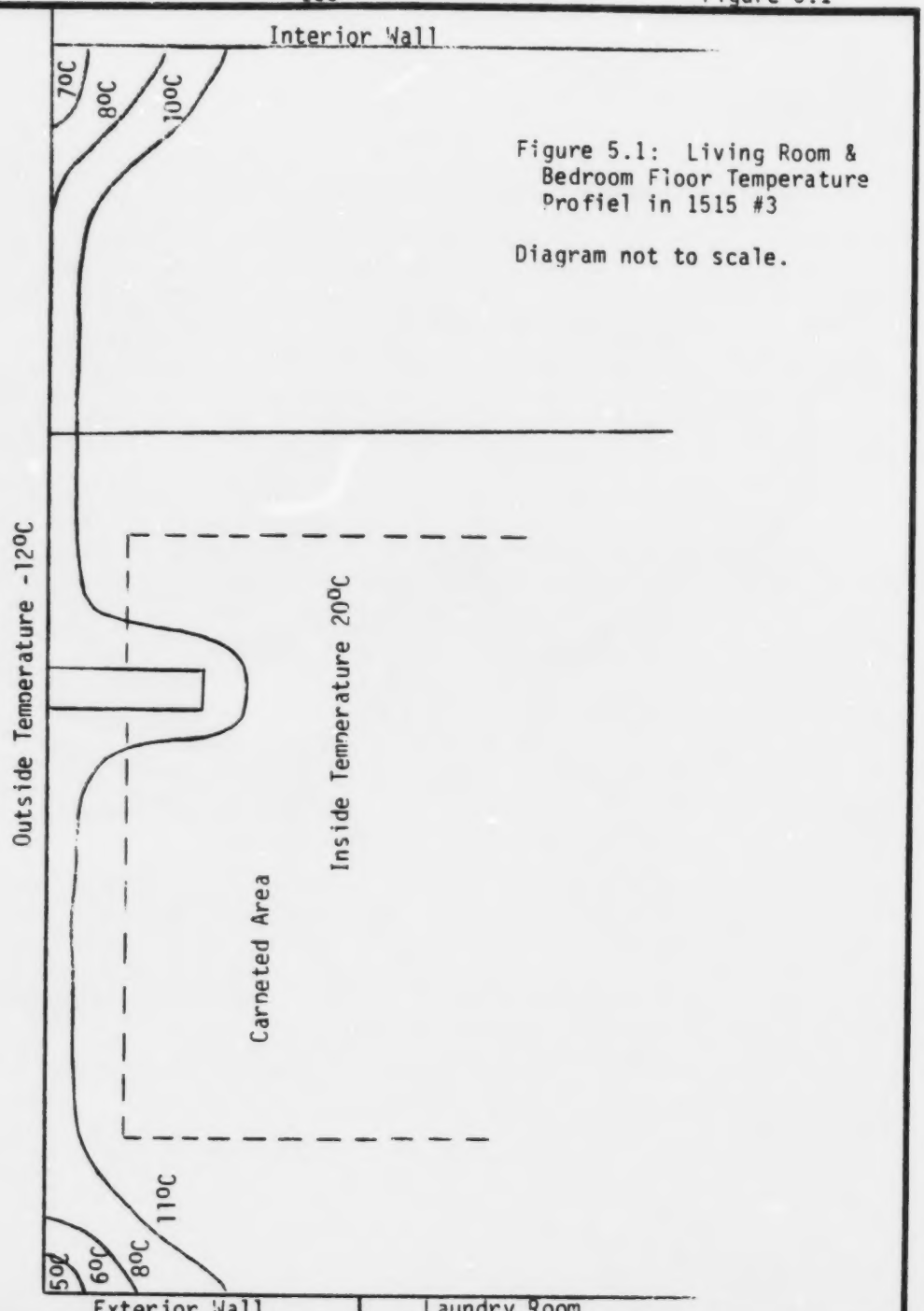

Figure 5.1: Living Room & Bedroom Floor Temperature Profiel in 1515 #3

Diagram not to scale.

Project: PRIMROSE CO-OPERATIVE

Title: TEMPERATURE PROFILE

ALLEN-DRERUP-WHITE LTD.
designers-builders and consultants
energy conservation, solar heating
(416) 863-1762
334 King St. E., Studio 505
Toronto, Ontario, M5A 1K8

Scale: N.T.S.

Date: 1/3/82

Ref. No.: 82-03

Drwg. No.: FIG. 5.1

Hughes-Owens Geovel

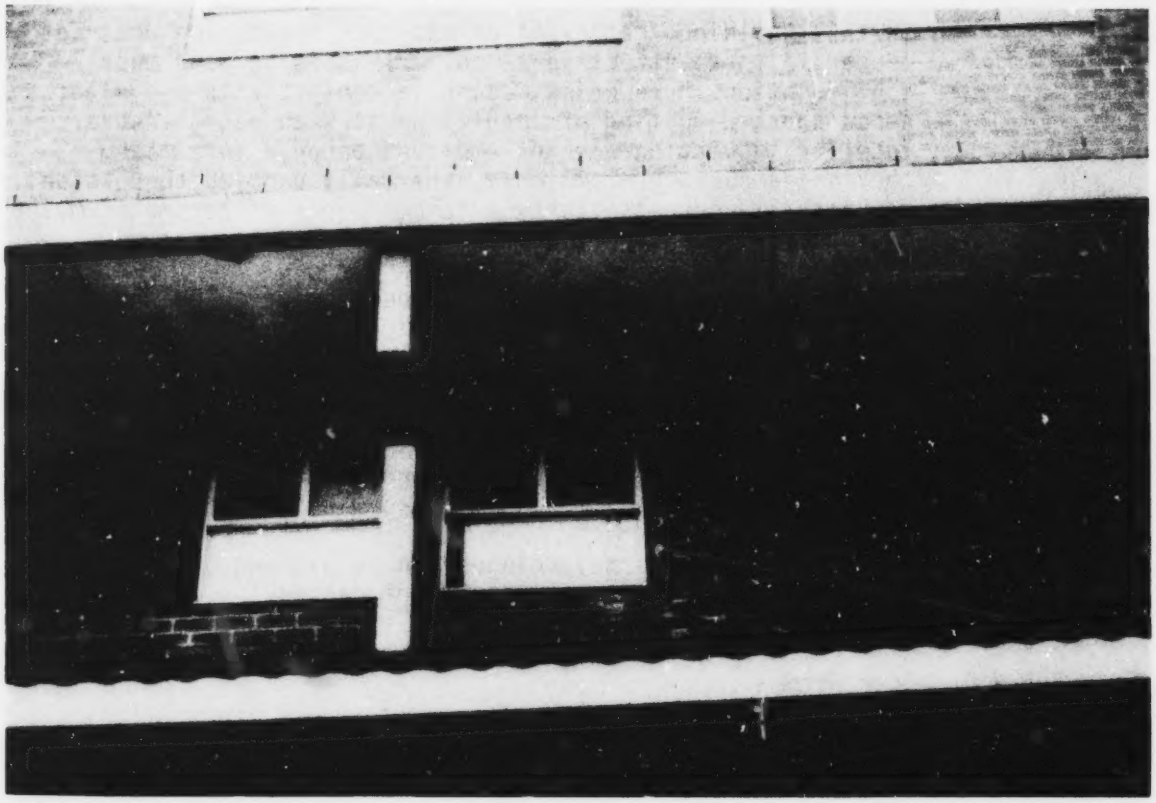

Photo 5-1 - Exterior, Block 2
Slab Overhang

Shearwall extension outside of
building creates thermal bridge
at connection to floor slab above.
See temperature profile following.

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5.2.1 Thermal Bridges (cont'd)

In this building, retro-fit of exterior insulation does not appear to be an effective remedy. This is becuase most configurations have brick facing in contact with the slab; hence short ciruiting of insulation at slab edges occurs. Interior insulation was not employed because insulating the inside surface of masonry, thermally exposed to outside, may actually decrease surface temperatures of perimeter masonry by reducing heat supplied from the heated space.

Heating of the floor slab itself does appear to be an effective and positive solution with only slight associated energy costs.

The existence of thermal bridges also represents a heat loss of significant proportion. For a typical slab edge, with brick veneer top and bottom the heat loss through the masonry (about 60 W/m of wall) is greater than through the rest of the insulated wall (RSI 2.1, assuming no windows, about 50 W/m).

Many structural thermal bridges can be avoided or minimized if they are addressed in the early stages of design.[3]

5.2.2 Door Frames

Formed steel door and window frame assemblies are installed in several locations in the building as part of the exterior fabric. These locations are typically: entrance door frames in townhouse units, balcony door frames and sidelites in apartment units, and fire exit door frames in two bedroom apartment units. Observations included copious surface condensation, rusting and damage of sill and wall surface directly below such frames. The predicted lowest surface temperature based on measurements and the outside design temperature is approximately 2°C (compared to 7°C for double glass) and the predicted period of condensation is 28 days (see 3.1.2 Location Type X).

The active mechanism in this case is the conductivity of the steel element coupled with its general arrangement. If the insulative components (door and window glass) had been located at the outside surface, if an insulating frame material had been used or a thermal break incorporated, the interior surface temperature would not be as low as it is at present, thus ameliorating or removing the problem.[1,5]

This type of door frame (i.e. thermally unbroken metal frame) is not compatible with the normal humidity levels which would be expected in a building of this type, since condensation can form on the frame prior to being evident on the interior surface of double glazing.

5.2.3 Window Frames

Although the window frames incorporate a thermal break, the frame surface temperature remains slightly lower than the glass temperature under cold weather conditions. Although the temperature difference is marginal in this case, it is sufficient to cause condensation on the frame elements prior to condensation occurrence on the main glass surface. Under these conditions, condensation can sometimes go undetected and result in damage to surrounding surfaces.

While these windows meet the applicable CMHC requirement for air-infiltration, there is at present no method of rating the effectiveness of the thermal break used. Reference 1 (CBD-4) recommended in 1960 that thermal breaks used in metal sash assemblies ensure temperatures equal to, or greater the lowest temperature expected on the glass surface it carries.

5.3 Lifestyle

Data from which the conclusions in this section are drawn are based on personal observation, interviews with Co-op members and administration personnel and the results of a questionnaire concerning living patterns which was distributed to all concerned units. The questionnaire form, as well as the tabular results are included in Appendices 1, 2 and 3. The questionnaire results for 1982 can be considered to be of high quality, with all but two returned and most questions answered.

Based on the above, it cannot be said that lifestyle is a prime determinant of occurrences of condensation. Examples exist of very high humidity lifestyles which produce no severe condensation occurrences (e.g. 1509, #11) and units which are lightly occupied and yet which exhibit fairly severe condensation events (e.g. 1505 #1).

It can be said however that among unit types that are prone to high humidity levels and/or damage (see 5.4 Technology) the severity, amount and duration of condensation is related to lifestyle. This is to say, in a unit which is not, by its position or configuration, prone to surface condensation, even a high-humidity lifestyle does not lead to problems and, in a unit that by its position, configuration or existence of thermal bridges will exhibit surface condensation, the severity of damage depends to a large extent on the humidity generation rate of the occupants.

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5.3 Lifestyle (cont'd)

In general, the occupants of the buildings in question lead lifestyles which do not lend themselves to high moisture generation rates. A high percentage of the apartment population are working couples both of whom are not home during the day. Of the townhouses most units have at least one occupant during daytime hours. Most laundry is done in the common laundry (apartments) or in basements and most drying is done in dryers which are vented (basements of townhouses). In no specific case could it be said that the level of moisture generation was significantly beyond what could be expected as a maximum given the size and living arrangements of a particular space.

Two operating modes were identified through interviews with occupants and co-operative staff as well as hygrothermograph testing which may contribute in some degree to condensation problems.

The first operating mode results from conscientious operation of the heating controls, that is, the room thermostat is turned down or off during unoccupied periods and at night. The resultant lowering of room temperatures results in lower surface temperature and increases the possibility of condensation. It should be pointed out that although relative humidity rises dramatically with a slight drop in temperature, the absolute moisture content and the dew point temperature do not change, if room-air temperatures are reduced resulting in lower surface temperature, condensation will result.

The second operating mode, observed in only one instance involved the use of a local, radiant type heater as an alternative to the installed baseboard convectors. The occupants perceived that the baseboards did not heat effectively and may have been reacting to the sometimes pronounced stratification which occurs when convection heating is combined with 'cool' floors. In any event, the use of such a local heater will produce surface temperature reductions of approximately the same magnitude as would result from turning down the thermostat, since comfort is maintained by radiant heat, not sensible air temperature.

5.4 Technology

The problems and mechanisms discussed in this section are categorized under 'Technology' because they are manifestations arising out of the present standards and practice of residential building in Ontario.

5.4.1 Tightness/Air Leakage

The measured infiltration rates of outside air when compared to the volume of the spaces are relatively low largely due to the small exterior wall surface in townhouses. It cannot be said however, that the exterior wall assemblies are as tight as their specification intended based on the previous de-pressurization test and field observations. It is interesting to note that the architectural specification called for interior caulking which was not done. Had this caulking been conscientiously applied the natural infiltration rate would have been lower than that now experienced.

The standard to which this building was built, (polyethylene vapour barrier, non-permeable sheathing) is higher than that which has historically been used for this type of building but but below present standards for co-operative housing (i.e. 1983 Measures for Energy Conservation, NRC).

It can be concluded that the tightness of these buildings is a contributory factor in the high humidity levels experienced inasmuch as natural infiltration and exfiltration does not exist in magnitudes corresponding to those experienced in buildings built to previous standards and methods. Lower natural infiltration rates lead naturally to higher levels of humidity as less dry outside air is available to displace moist, interior air thus reducing the building's capacity to relieve internally generated moisture.

In view of the low levels of natural (fresh) air change recorded in this case, i.e. 0.2 air changes/hour (17 l/s) for townhouse units and for apartment units according to the ventilation analysis of Section 4.5.4, it can be concluded that additional ventilation means, other than natural air leakage or fans which are suitable only for short-term use, should be provided for buildings of this specification. If the building had been built as the designers intended, natural air change rates would have been lower than those measured.

5.4.2 Stack Effect

As concluded from the results of the tracer gas testing most of the air moving through the apartment under test was being supplied from the townhouses below. This is reinforced by smoke pencil observations which show infiltration at lower townhouse levels, exfiltration at upper townhouse and apartment levels and strong air movement into and out from the plumbing chase. Hygrothermograph results do not conclusively point to stack effect, as the moisture level in upper units does not 'follow' that in lower units but nevertheless indicate a strong influence as the humidity level in an upper unit will remain at a high level, even during unoccupied periods. From field observations it can be clearly seen that moisture damage is concentrated in upper units rather than lower units.

Stack effect, or the movement of air from lower units to upper units contributes to elevated humidity levels in that the air entering upper units is not dry outside air as it is in the lower units but rather is air that already contains a moderate amount of humidity. The addition of humidity from normal activities to this air then results in elevated humidity levels.

The Ontario Building Code Section 9.10.10. Fire Stopping calls for the use of firestops at floor levels in chases such as the plumbing shaft previously mentioned. Judging from the magnitude of air movement this firestopping is probably not present.

The results of the trial which involved sealing the air-passage routes between lower and upper units did not produce an apparent change. This may have been as a result of the lack of success encountered in obtaining higher ventilation rates, or it is possible that all routes of air movement were not able to be sealed. It is also possible that air-sealing of the passages from lower to upper units, reduced the magnitude of air pressure due to stack effect, resulting in a lower overall air change rate.

In the event that major air paths continue to exist between upper and lower units, exhaust only ventilation could not be counted on to be effective as "second hand" air is being drawn into the upper units. In this case a positive supply of fresh air to the upper units would be required via the hallway.

Stack effect is normally present in all buildings during cold weather. In modern low rise construction, conditions such as are present here, where the neutral plane (level where infiltration changes to exfiltration) exists in the approximate middle of the structure, occur frequently without significant problems. The principal difference is that when units are not 'stacked' the air moves into, and thus out from, the same unit rather than moisture laden (stale) air passing from a lower to an upper unit.

5.4.2 Stack Effect (cont'd)

In a house with combustion heating, significant natural ventilation is provided by the stack effect of the flue and a relatively dry environment is maintained.

The subject buildings, which are heated electrically and have no flues, do not exhibit any of the above desirable characteristics and so experience principally the negative aspects of this mechanism.

5.4.3 Ventilation

Existing manually controlled ventilation fans were found to operate properly with air flow rates in the range of 50 l/s for kitchen fans and somewhat less for bathroom fans.

Except for the one bedroom apartments of Block 2 which were equipped with cabinet type exhausters (in which the fan is enclosed in a metal cainbet and ducted remote from the intake location), the existing fans are noisy so it is suspected that they are used only to relieve odour and cooking fumes.

While this ventilation arrangement is the norm for townhouse construction, problems are usually not encountered due to the absence of additional units above the principle living space, i.e. stack effect does not play a role, as units are not 'stacked'.

The type of housing construction, low natural infiltration rates, movement of stale air into upper units and lack of continuous, positive ventilation result in conditions which lead to unacceptably high internal humidity levels during normal occupation. Results of the ventilation trial carried out have shown that existing exhausters in the upper units of Block 2 can be effective if run continuously; however, the magnitude of actual outside air change produced by their operation has not been established.

5.4.4 High Insulation Levels

High insulation levels cannot be considered to contribute to the problems under consideration in any direct manner. The use of construction systems with higher levels of air tightness, a corollary of higher insulation levels is, however, a contributing factor, and is discussed in 5.4.1, Tightness/Air Leakage.

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6. Standard Practice for Measuring Air Leakage Rate by the Tracer Dilution Method, ASTM E 741-80

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APPENDICES

1. Questionnaire Form

2. Summary Tabulation of Questionnaire Results - 1982

3. Summary Tabulation of Questionnaire Results - 1983

4. Prediction of Surface Temperatures

5. Surface Condensation as a Function of Outdoor Temperature and Indoor R.H. - Discussion

6. Report on SF_6 Testing at 1541 Davenport Road
prepared by MacLaren Engineers, Planners & Scientists Inc., February 1982

7. Analysis of insulation vs. slab heating

8. Moisture Induced Problems in NHA Housing
Part 2 of 3 Literature Review & Research, Extract from;
Section 3.0 - Mould & Mildew on Room Side Surface Enclosures.
J. Timusk, Ph.D with Marshall, Macklin, Monaghan Ltd. for CMHC

APPENDIX 1

ALLEN-DRERUP-WHITE LTD.

designers-builders, consultants, energy conservation and solar heating

334 King Street East, Studio 505
Toronto, Ontario M5A 1K8
(416) 863-1762

Dear Co-operative Member:

In order to find out the causes for the water damage at floors, ceilings, exterior walls, interior of closets and around door and window frames, we require your co-operation.

The following is a simple questionnaire. Would you kindly fill it out and leave it outside your door tomorrow morning. Someone will come and pick it up.

Thank you for your co-operation.

Yours truly,

ALLEN-DRERUP-WHITE LTD.
Consultants

SC:nf
Encl.

APPENDIX 1

1. NAME:

   ADDRESS:

2. Type of unit:

   (a) one bedroom apartment _____
   (b) two bedroom townhouse _____
   (c) three bedroom townhouse _____
   (d) four bedroom townhouse _____
   (e) two bedroom apartment _____

3. Number of people in the house:

   Adults _____ Children _____ (Please note ages of children)
   Pets (specify type and number) _____

4. What is the nature of occupancy? (Please fill in number of people)

   _____ people stay in the house all day

   _____ people stay in the house at night only

5. How many meals do you cook at home each day?

   (a) One ___ (b) Two ___ (c) Three ___ (d) None ___

6. How many people take a shower/bath every day? _____

7. Do you have any plants in the house?

   (a) 5 or less _____
   (b) 5 to 10 _____
   (c) more than 10 _____
   (d) none _____

8. How often do you do your laundry? _____

   Where? _____

   Do you use a clothes dryer, or are the clothes hung to dry? _____

   _____

9. Do you use a humidifier? _____

   Where is it located? _____

   How often is it operated? _____

10. Do you feel a draft anywhere in the house? If yes, please indicate the location by a sketch and how serious. _____

11. Do you experience fogging of the windows and if so:

    (1) How often? _____

    (2) On the inside glass or outside? _____

12. Is there any condensation in your house, such as wet or frozen windows, walls and floors etc.? If there is, please indicate the location by a sketch, and indicate how serious and if there is any degredation such as staining or tiles lifting.

    Does it occur: Rarely _____
    Sometimes _____
    Often _____
    Continuously _____

13. Do you sometimes notice smells from other apartment or townhouse units inside your unit (e.g. smoking or cooking)? _____

14. Do you feel that the air in your home is: Too humid _____ Too dry _____?

APPENDIX 2

SUMMARY OF QUESTIONNAIRE RESULTS

PRIMROSE CO-OPERATIVE

1982

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
# of adults/children/pets	2/2/2	2	2/1/1	2/1/0	2/0/0	2	1	2/1/2	-	-		
# in house all day/night only	night only	1		2/1	two	1	N	1	2	1	1	
# of plants	>10	X	>10	5<	>5	5<	5	>15	5-10	5		
# of cooking/day	1	1	1	1	1	1	1	1	1	1		
# fish meals/day	1	2	1	2	0	2	1	2	-	2	-	
# of showers/week	1/C.L.	2/C.L.	1/C.L.	2/C.L.	1	1	1	1/2 C.L.	1 C.L.	1 C.L.	6	
Dryer / hang dry	/	mixed	Dryer	Dryer	dryer	/		-	hang	dryer		
Use of humidifier	X	X	X	X	X	2	✓	X	X	X	X	
Use often						1/2 time	Dry					
Draft	✓	✓ *	✓ *	✓	✓	✓ **	X	✓	X	✓		
Smell	X	X	X	✓	X	X	✓	X	X			
Humidity in house	High	Dry	Normal	High	High	Sweating	Dry	-				
Indoors - Fog, "/cut,	C little	X	O heavy	C, heavy	C, heavy	C, heavy		C little	heavy			
- Mist, "/cut				C	C					C		
- Frozen "/cut	Some	Some	O, Some									
- Snow		✓				✓						
Floor - Wet,				C								
(Name) - Frozen	Some				Some							
- Warped	Some											
- Small		✓	✓	✓	✓							
Ceiling - Water mark				✓		✓ **				✓		
- Mold				✓	✓							
- Wet						✓ **						
Wall - Mold	Some											
- Wet	Some				Some	✓		C		✓		
- Frozen												
Floor - Wet						✓	✓					
- Water						✓				✓		
- Frozen									✓			
- Water damage				✓								
- Lifted tiles				✓		✓			✓			
*												
**	Some											
***	Some											

ISO	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
# of adults/children/pets												
# in house all day/night only												
# of plants	5-10		>10	5<				>10	5<			
# of cooking/day		1	2	2								
# of showers/day	2	2		1			1					
# of laundry/wk			2								2	
Dryer/hang dry				Dryer				Dryer				Dryer
Use of humidifier	X	X	X	X			X					
How often								S				C
Draft				0								X
Smell	X		X	X			X					
Humidity in house	Dry	Dry	Dry	Dry			Dry	Dry				OK
Windows - Fog, in/out				S								
- Wet, in/out		C		S			C	C	C			C
- Frozen, in/out												C
- Draft												
Doors (frame) - Wet												
- Frozen												
- Warped												
- Draft												
Ceiling - Water mark												
- Mold												
- Wet												
Wall - Mold												
- Wet												
- Frozen												
Floor - Wet							C					
- Water												
- Frozen	S			S								
- Water damage												
- Lifted tiles												
CL												
BL												

APPENDIX 2

1509	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
# of adults/children/pets	2/0/0	2/0/0	3/1/0	2/2/0	3/2/0	2/1/2	3/1/0	1/2/0	1/2/0	2/2/0	2/2/1	2
# in house all day/night only	3 Night	2/2	3/1	1/2	Night	2/1	DAY	Night	2/0	Night	Night	
# of plants	X	5-10	0	5-10	5-10	>10	5-10	>10	0-3	>10	5	-
# of cooking/day	2	2-3	1	1	1	2	2	2	1	2	3	
# of showers/day	0	1	1	1	3	3	3	1		2	2	
# of laundry/wk	½ F.L.	1/B.L.	2/2 L.	2/2 L	2-3/B.L.	1/B.L.	X	1/2 L.	1/2 L.	1/B.L.	3 B.L.	
Days/hours dry	B.L. C.L.	Dryer	Dryer	Dryer	Both	Dryer	X	Dryer	Dryer	Dryer	Dryer	
Use of humidifier	X	2x/D. Several	X	X	X	X	X	V (Bedroom)	X	X		
How often		3/week						Nights			Seldom	
Draft	/	√	√	√	√	X	X	√	√	X	√	
Smell	X	X	X	S.	√	X	X	X	X	X	√	
Humidity in House	/	Dry top bedroom, other OK	either	Dry	Dry	Dry	OK	Dry	Dry	Dry	OK	Dry
Indoors - "Fog", "/out.	S. both.	Some in	C with	some	Some	√	X	Some	/	Some	\	
- Wet, "/out.	0 (2nd floor)	Some				C					Some	
- Frozen, "/out.	0 (2nd floor)	S	C	S		Some	/	Some	√			
- Dust					√ Fan							
Door - Wet,												
(frame) - Frozen				S								
- Warped												
- Dust								Some				
Ceiling - Water mark												
- Mold												
- Wet									Some			
Wall - Mold												
- Wet,												
- Frozen,		S										
Floor - Wet,												
- Water,										Some		
- Frozen,		Some								Some		
- Water damage			Some									
- Lifted tiles												
									Some			

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
# of adults/children/pets	[illegible]	2/3/1	1/c/1	1	[illegible]	[illegible]	1/0/0					
# in house all day/night only	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
# of plants	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	C	[illegible]					
# of cooking/day	1	2	1	1	[illegible]	1	1					
# of showers/day	1	2	✓	1	[illegible]	[illegible]	0					
# of laundry/wk	1/c.l.	[illegible]	1/c.l.		1/c.l.	[illegible]	[illegible]					
Dryer / hang dry	dryer	dryer	dryer		[illegible]	Dryer	[illegible]					
Use of humidifier	X	X	[illegible]	\	X	X	X					
How often			C									
Draft	✓	✓	X	✓	✓	-	✓					
Smell	X	✓	X		S when [illegible]	X	X					
Humidity in house	Dry	Dry	Dry	Dry	Vinyl							
Windows - Fog, in/out,		- outside		✓ [illegible]	C l.		C. l.					
- Wet, in/out.						C	C					
- Frozen, in/out.	[illegible]		St.		[illegible]	C						
- Draft		✓										
Floor - Wet,												
(Warped) - Frozen												
- Warped												
- Draft		✓										
Ceiling - Water mark												
- Mold			O									
- Wet.												
Wall - Mold												
- Wet.												
- Frozen,							C					
							[illegible]					
Floor - Wet,			C		C							
- Water,												
- Frozen.												
- Water damage												
- Lifted tiles						[illegible]						
[illegible]												

APPENDIX 3

SUMMARY OF QUESTIONNAIRE RESULTS

PRIMROSE CO-OPERATIVE

APPENDIX 3

ALLEN-DRERUP-WHITE LTD.

low energy buildings — engineering, consulting, design and construction

334 King Street East, Studio 505
Toronto, Ontario M5A 1K8
(416) 863-1762

Dear Co-operative Member:

In order to update our research concerning water damage at floors, ceilings, exterior walls, interior of closets and around door and window frames, we require your co-operation.

The following is a simple questionnaire. Would you kindly fill it out and leave it outside your door tomorrow morning. Someone will come and pick it up.

Thank you for your co-operation.

Yours truly,

ALLEN-DRERUP-WHITE LTD.
Consultants

DB:jb
encl.

1. NAME:

   ADDRESS:

2. Type of unit:

   (a) one bedroom apartment _____
   (b) two bedroom townhouse _____
   (c) three bedroom townhouse _____
   (d) four bedroom townhouse _____
   (e) two bedroom apartment _____

3. Number of people in the house:

   Adults _____ Children _____ (Please note ages of children)
   Pets (specify type and number) _____

4. What is the nature of occupancy? (Please fill in number of people)

   _____ people stay in the house all day

   _____ people stay in the house at night only

5. How many meals do you cook at home each day?

   (a) One ___ (b) Two ___ (c) Three ___ (d) None ___

6. How many people take a shower/bath every day? _____

7. Do you have any plants in the house?

   (a) 5 or less ____
   (b) 5 to 10 ____
   (c) more than 10 ____
   (d) none ____

8. How often do you do your laundry? _____

   Where? _____

   Do you use a clothes dryer, or are the clothes hung to dry? _____

   _____

9. Do you use a humidifier? _____

   Where is it located? _____

   How often is it operated? _____

10. Do you feel a draft anywhere in the house? If yes, please indicate the location by a sketch and how serious. _____

11. Do you experience fogging of the windows and if so:

    (1) How often? _____

    (2) On the inside glass or outside? _____

12. A) If your unit is equipped with a fan speed control:

    (1) Do you operate the fan using the speed control? Yes _____ No _____

    or the wall switch Yes _____ No _____

    (2) If you are using the speed control, where is it set?

    _____

    (3) Do you change the setting when you leave or return home?

    _____

    (4) Has there been any change in window fogging after installation of controls?

    _____

    (5) Are you able to affect humidity reading by turning fan up or down (after a day or two)?

    _____

    B) If your unit has a basement fan and switch:

    (1) Do you operate the basement fan and if so, when and for how long?

    _____

    _____

B) (2) Are you able to affect the humidity level by running the fan? (after a couple of days) _____

_____

(3) Do you find that window fogging is reduced by running the fans or has been less after the switches were installed?

_____

_____

13. Do you sometimes notice smells from other apartment or townhouse units inside your unit (e.g. smoking or cooking)? _____

14. Do you feel that the air in your home is: Too humid_____ Too dry_____?

15. Has there been condensation in your house over this past winter, such as wet or frozen windows, walls and floors, etc.? If there is, please indicate the location by a sketch, and indicate how serious and if there is any degredation such as staining or tiles lifting.

Does it occur: Rarely _____

Sometimes _____

Often _____

Continuously _____

APPENDIX 3

PROBLEM - DIP ISSUE	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
# of outlets/fixtures				1/1/1							
Type of fixture affected (light switch, outlet)				1 1							
# of plates											
# of switches/device				2							
# of circuits/device				1½							
# of damaged/leaky pipes / time elapsed				L /							
Use of humidifier Hours used				X /							
Dark				√ DOOR TO LIVING ROOM							
Smell											
Humidity in house				HUMID EVER A.M.							
Windows - Type, #/unit				C							
- Leak, #/unit											
- Trapped #/unit				ALL C							
- Insect											
Door (frame) - Wet											
- Fungus											
- Warp											
- Smell											
Ceiling - Wet											
- Mold											
- Wet				C							
Wall - Mold											
- Wet											
- Fungus											
Floor - Wet											
- Water											
- Fungus											
- Water damage											
- Lifted tiles											

ABBREVIATIONS: L-basement laundry C-common room

C-constantly
O-often
S-sometimes
R-rarely

*NOT HEATED
** SEE NOTES
*** HEAT SEE NOTES

/ yes
X - no
/ - discovery

1505

APPENDIX 3

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
12A) USE SPEED CONTROL?		X										
USE MANUAL?		/		/								
2) SETTING FOR SPEED CONTROL												
3) CHANGE SETTING WHEN LOOK HOME?												
4) CHANGE IN WINDOW FOGGING?												
5) AFFECT HUMIDITY BY TURNING FAN ON OR OFF?												
B)1) BALANCED FAN?												
HOW LONG (HR)?												
2) AFFECT HOW OFTEN BY PUSHING REMOTE FAN?												
3) WINDOW FOGGING REDUCED?												

APPENDIX B

15th Interval											
# of adults/children /p.t.				2/0/1							
Time in home all day/night/sleep				=/2							
# of plants				5 to 10							
# of cooking/day				1							
# of showers/day				2							
# of laundry/wk Days/hours day				2 x Wk AFTER 6PM							
Use of humidifier Hr. on time				X /							
Dust				~~HEAVY~~ UPON WINDOW SILL							
Smell				X							
Humidity in house				50% TO 60%							
Windows - Type, #/cnt, - Dust, #/cnt, - Trapped #/cnt - Condensation				DISPOSABLE DEHUMIDIFIER IN BEDROOM, DUST THERE AIR /							
Door (frame) - Dust - Trapped - Warped - Cracked											
Ceiling - Dust - Mold - Wet											
Wall - Mold - Dust - Trapped											
Floor - Wet, - Water, - Trapped, - Water damage - Lifted tiles				CLOSET MAJORITY, LEVEL OF							

PERFORMANCE of L-basement laundry
C-constantly C-clothes washer
O-often
S-sometimes
R-rarely

* NOT VERY SERIOUS
** SERIOUS
*** VERY SERIOUS

laundry room
X-yes
/-occasionally

APPENDIX 3

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
12A) USE SPEED CONTROL?				/								
USE MECHANICAL?				/								
2) SETTING FOR SPEED CONTROL				/								
3) CHANGE SETTING WHEN IN A HOME?				/								
4) CHANGE WINDOW FOGGING?				/								
5) AFFECT HUMIDITY BY TURNING FAN [illegible]												
B) 1) BALANCE FAN? HOW LONG? ✓				FAN BACK ON								
2) AFFECT HOW DRY BY RUNNING EXHAUST FAN?				→ ON AFT 2 DAY								
3) WINDOW FOGGING REDUCED?				✓								

APPENDIX 3

# of exhibit/visitors/pt.		≤1/10	3/1/0								
Time in home all day/night only		2/1	2/2								
# of pets			<5								
# of cockroaches/day		3	2	1							
# of flies/day			2	1							
# of dampdays/wk Days/humidifier		1, B.L.	1, C.L.	1							
Use of humidifier Hrs. of use		✓ 1-2x/WK (WINTER)	X								
Dust		FREQUENT	FREQUENT								
Smell		✓MOLD MA'S	X								
Humidity in house		R, DRY	S, WET in WINTER								
Windows - Frost/day - Wet/day - Tears/day - Ice		SPROFL BLEEDING CONDEN									
Doors (floors) - Wet - Frozen - Warped - Frost											
Ceiling - Wet/drip - Mold - Wet											
Wall - Mold - Wet - Frozen											
Floor - Wet - Water - Frozen - Water damage - Lifted tiles		S, RAIN→ SPILLING ICE ON WINDOW (EFFUSIVE)									
(DOESN'T APPLY)			S								

ABBREVIATIONS: B-basement bedroom, L-bathroom, C-common room

C-constantly, O-often, S-sometimes, R-rarely

*NOT VERY SERIOUS

**SERIOUS

***VERY SERIOUS

W-WALL

✓-yes, X-yes, /-occasionally

1509	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
12A) USE SPEED CONTROL?		/	/								X	
USE MED SPEED?		/	/								/	
2) SETTING FOR SPEED CONTROL			/									
3) CHANGE SETTING WHEN TEMP HOME?		/	/								X	
4) CHANGE HUMIDITY FOCUSING?		/									X	
5) AFFECT HUMIDITY BY TURNING FAN ON/OFF?				TO							\	
B) 1) BALANCE FAN HOT LOW/HI		✓ C	✓ C	ALL DAY								
2) AFFECT HOW LONG DEHUMIDIFIER RUNS?		SOME	X	NO								
3) HUMIDISTAT POINT SHOULD BE REDUCED?		X	SOME	NO CHANGE UNLESS WINDOW OPEN								

APPENDIX 3

ISLE	#1			#6	#2	#4	#7				
# of individual rms./pets				Vac's	2/0's	2's	Vac's				
Inside/outside cats					1/1	2/1	1/0				
# of plants				LOTS	SOME		LOTS				
# of cooking/day			1	1		1	2				
# of showers/day				1	1	2	1				
# of laundry/wk			½ LOAD	2 CYCLES	1 CYCLE	1 LOAD	½ CYCLE				
Dryer/hang dry				DRYER	MIXED		DRYER				
Use of humidifier			X	✓	X		X				
Hours often/wk				0→4							
Dampness				**	X		*BASEMENT ONLY				
Smell			1 CAT	X	✓ IN BATHROOM	NO	✓				
Humidity in house			OK	DRY	HUMID		DRY				
Windows - Type, #/wk.			LOOK LIKE IT	ONLY IN COOL	CASEMENT OPEN IN		5 WINDOWS				
- Use, #/wk.					O. FRAME		✓				
- Type, #/wk							✓				
-											
-											
Door - Use,							✓				
(Frame) - Type							✓				
- Warp											
- Draft											
Ceiling - Use, wash											
- Mold							**				
- Wet											
Wall - Mold											
- Wet,				IN CLOSET			**C MEDIUM				
- Type,											
Floor - Wet,			SLIGHTLY		AT DRY WALL/ESP SIDE	5					
- Water,											
- Type,											
- Water damage				SLIGHT		5	SLIGHT				
- Lifted tiles						5					

ABBREVIATIONS:										
C-continuously	ISLE-basement laundry room	*NOT YET CERTAIN								
O-often	ISLE-common laundry room	** SEE ABOVE								
S-sometimes	X-yes									
R-rarely	/-occasionally	*** VERY SEVERE	#2	#5	#6	#7	#3	#4		

1515

APPENDIX 3

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
12A) USE SPEED CONTROL?			✓	✓	X		S					
USE MODE SWITCH?					✓		✓					
2) SETTING FOR SPEED CONTROL												
3) CHANGE SETTING WHEN AT HOME?				X			X					
4) CHANGE WINDOW FOGGING?					✓	✓	SAME					
5) AFFECT HUMIDITY BY TURNING FAN ON/OFF?					✓							
B) 1) BALANCING FAN HORIZONTAL?							X					
2) AFFECT HOW QUICKLY DEFOG/DEICE FAN?												
3) WINDOW FOGGING REDUCED?												

PREDICTION OF SURFACE TEMPERATURE

The equation for predicting the temperature of the surface of interest at design condition is derived as follows:

Let T_i, T_o and T_s be the indoor, outdoor and surface temperature at time of measurement.

Let T_{iD}, T_{oD} and T_{sD} be the indoor, outdoor and surface temperature at design condition.

Let $(T_i - T_s) = \Delta T_{is}$

Let $(T_i - T_o) = \Delta T_{io}$

Let $(T_{iD} - T_{sD}) = \Delta T_{isD}$

Let $(T_{iD} - T_{oD}) = \Delta T_{ioD}$

Let U_i be the coefficient of transmission for interior surface.

Let U_{io} be the overall coeficient of transmission between indoor and outdoor air.

The heat flow across a wall is given by: $Q = UA\Delta T$

or: $Q/A = q = U\Delta T$

Based on this, the heat flow per unit area between the room and the inside surface is given by: $q = U_i\Delta T_{is} = x$

but: $U_{io}\Delta T_{io} = x$

$$U_{io} = \frac{x}{T_{io}} = \frac{U_i\Delta T_{is}}{\Delta T_{io}}$$

Assuming the coefficients of transmission are approximately the same under design condition ($T_{iD} = 20^oC$, RH = 40%, $T_{oD} = -20^oC$)

$$U_{io}\,\Delta T_{ioD} = y$$

but $y = U_i\Delta T_{isD}$

$$T_{isD} = \frac{y}{U_i} = \frac{U_{io}\Delta T_{ioD}}{U_i}$$

$$\text{but } U_{io} = \frac{U_i \Delta T_{is}}{T_{io}}$$

$$\Delta T_{isD} = \frac{U_i \Delta T_{is}}{\Delta T_{io}} \cdot \frac{\Delta T_{ioD}}{U_i}$$

$$\text{or } (T_{iD} - T_{sD}) = \frac{(\Delta T_{is})\ (\Delta T_{ioD})}{\Delta T_{io}} \qquad \text{equation 1}$$

$$T_{sD} = T_{iD} - \frac{(\Delta T_{is})\ (\Delta T_{ioD})}{(\Delta T_{io}} \qquad \text{equation 2}$$

Rearranging equation 1:

$$T_{oD} = T_{io} - \frac{(\Delta T_{isD})\ (\Delta T_{io})}{(\Delta T_{is})} \qquad \text{equation 3}$$

To find the outside temperature at which the inside surface will start to have condensation at 20°C, 40% RH (Dew point Temperature = 7°C)

$$T_{oD} = 20 - \frac{(13)(\Delta T_{io})}{(\Delta T_{is})} \qquad \text{equation 4}$$

Similarly, the outside temperature at which the inside surface will start to freeze is

$$T_{oD} = 20 - \frac{(20)\ (\Delta T_{io})}{(\Delta T_{is})} \qquad \text{equation 5}$$

Surface Condensation as a Function of Outside Temperature & Indoor R.H. - Discussion

The following calculations are made based on design conditions (i.e. Inside temperature = 20°C, 40% RH, Outside temperature = -20°C). Any variation from the design conditions will alternate the final outcome especially in the marginal cases. To demonstrate this effect, let's take the balcony (or fire exit) door frame as example:

Temperature Measured:

Indoor: 21°C Outdoor: 1°C Surface: 12°C

From equation 2, the predicated surface temperature at design condition:

$$T_{sD} = 20 - \frac{(20 - (-20))\ (21 - 12)}{(21 - 1)}$$

$$= 2°C$$

From equation 4, the predicted outside temperature for condensation at inside surface is:

$$T_{oD} = 20 - \frac{(20 - 7)(21 - 1)}{(21 - 12)}$$

$$= -9°C$$

From hourly data summaries - No. 3R, the period for outside temperature below -9°C is 7.8% of the year or 28 days. If the relative humidity in the apartment is raised to 50%, the corresponding dew point temperature is 10°C. The outside temperature for condensation at inside surface is therefore:

$$T_{oD} = 20 - \frac{(20 - 10)(21 - 1)}{(21 - 12)}$$

$$= -2°C$$

This represents 15% of a year or 56 days. From the above example calculation, the effect of raising the humidity level is obvious. It was noted that many of the units visited have humidity levels above 40%.

APPENDIX 6

REPORT ON SF_6 TESTING

AT 1541 DAVENPORT ROAD

FOR

ALLEN-DRERUP-WHITE LTD.

BY

MacLAREN ENGINEERS PLANNERS & SCIENTISTS INC.

February 1982

REPORT ON SF_6 TESTING AT 1541 DAVENPORT ROAD FOR ALLEN-DRERUP-WHITE LTD.

INTRODUCTION

The apartment/townhouse complex at 1541 Davenport Road has been experiencing condensation on the floors and ceilings of some of the apartment units. In order to address this problem, it was considered appropriate to establish whether air exchange from the townhouses below to the apartment units was taking place through the pipe plenum connecting the upper and lower units and to determine an air change rate for these units.

For this analysis, the tracer gas dilution method was used, and sulfur hexafloride (SF_6) served as the tracer gas for the sampling.

SF_6 was considered appropriate since it can be measured in concentrations of a few parts per billion with an electron capture detector after separation from oxygen chromatographically as part of the analytical procedure. It is non-flammable and comparatively non-toxic. SF_6 is quite inert, has a very low solubility in water, and can withstand high temperatures before decomposing. It does not occur naturally and is slightly heavier than air.

Preparation of the Structure

Windows and doors were closed to the exterior and exterior vent systems were off. All interior doors were open, closets were open to eliminate dead air spaces, and electric fans were moved about to achieve thorough mixing of air prior to the sampling period.

Sampling Procedure

5 February 1982 - Townhouse Units Nos. 3 and 4

Twenty-five cubic centimetres (cc) of SF_6 tracer gas were released on each of four floors in the two downstairs townhouses (Units 3 and 4), giving a total of 100 cc of SF_6 per townhouse.

For this building, with baseboard electric heating, it was considered necessary to provide mechanical mixing of the tracer gas by fans prior to the first sampling period. In Unit 4, the mixing took place for 20 minutes of each half-hour sampling period. This extra mixing did not appear to affect the results.

In both townhouse units air samples were drawn from the room air on each of the top three floors every half hour over a total period of four hours for later analysis.

In order to determine if air were moving from the two townhouse units to the apartment above, air samples were drawn from the pipe plenum in the bathroom, in the bathroom itself and from the living room of the apartment every half hour over the four-hour test period. No tracer gas was injected and no mechanical air mixing took place in the apartment.

10 February 1982 - Apartment Unit No. 3

In order to determine the air change rate for apartment Unit 3, a second day of testing was necessary. Fifty cubic centimetres of tracer gas were released within the apartment and mixed using fans for a period of 15 minutes. Sampling took place at 15 minute-intervals for the first half hour and then every half hour for a total test period of four hours. The test results for both days follow:

Test Results 5 February 1982

For the analysis of the air change rate, if the natural logarithm of the concentration (on a linear scale) is plotted against time in hours, the measurements should fall on a straight line provided the air change rate remains constant. A scatter of points is expected and a straight line best fit was calculated using a linear regression analysis for the data.

The slope of the line is given by:

$$S = \frac{\ln C_1 - \ln C_2}{t_2 - t_1} \quad \text{where}$$

C_1 = concentration at time 1 (t_1)

C_2 = concentration at time 2 (t_2)

Therefore, the slope of this line yields a rate of change in the concentration of the tracer gas with time or the air change rate per hour.

The following are the results of the linear regression analysis performed on the data for townhouse units 3 and 4:

Table 1

Date	Unit	Floor	Intercept (ln Conc.)	Air Change Rate (Slope)	Correlation	Average Air Change Rate
5/02/82	Townhouse No. 3	1	3.9964	-0.2084	-0.9952	-0.20 (Air Changes/hr)
		2	4.0514	-0.1745	-0.9989	
		3	4.0807	-0.2297	-0.9902	
5/02/82	Townhouse No. 4	1	4.0807	-0.2048	-0.9986	-0.21 (Air Changes/hr)
		2	4.1560	-0.2032	-0.9996	
		3	4.2129	-0.2102	-0.9998	

From Table 1 it can be seen that the air change rate for units 3 and 4 is approximately 0.2 air changes per hour, or one air change in five hours.

The data exhibits a good correlation between the SF_6 concentration and time. The average slope and the natural logarithms of the concentrations are plotted on fig. 1.

From the plans of the townhouse units, the calculated volume is approximately 11,100 cubic feet. If this is reduced by 10% for furnishings, the average volume of air change per unit is approximately 2,000 cubic feet per hour. This air change rate would be considered very low.

Figure 2 shows the results of the tracer decay testing in apartment No. 3 on 5 February 1982.

Test Results 10 February 1982

Table 2 presents the results of the linear regression analysis performed on the test data for apartment 3 on 10 February 1982.

Table 2

Date	Unit	Location	Intercept. (ln conc.)	Air Change Rate (Slope)	Correlation	Average Air Change Rate
10/02/82	Apartment No. 3	Bedroom	4.397	-0.656	-0.999	-0.63 (Air Changes/hr)
		Living Room	4.288	-0.612	-0.997	

The volume of the apartment unit was calculated at 4,440 ft^3. Again, reducing by 10% for furnishings gives a total volume at an air change rate of 0.63, of 2,520 ft^3 per hour. The test results are plotted on fig. 3.

Conclusions

It should be noted that in both townhouse units, the third floor exhibits the highest concentrations of tracer gas, with the second floor next and the first floor showing the lowest concentrations. Although this trend is not great enough to skew the data, it does confirm a tendency for the air within the units to migrate from the lower levels to the upper floors with the stack effect. This tendency is also apparent in the movement of tracer gas through the pipe plenum into the upper apartment unit.

Analysis of the results of apartment No. 3 testing on 5 February 1982, shows that the pipe plenum appears to be a major route for air exchange from the townhouse units below. Tracer gas appears in the pipe plenum at a high level for the first sample. While the levels in the two townhouse units, for the first sample, range from 48.3 to 66.9 ppb, the level in the plenum at the same time is already at 44.5 ppb. In fact, the level within the pipe plenum peaks within the first half hour and then exhibits a decay curve similar to the two townhouses below. This suggests that the pipe plenum is a major source of air movement between the townhouse and the apartment.

SF_6 sampling in the bathroom and living room of the apartment as well as the outside corridor, also tends to verify this conclusion. (See fig. 2.) If the plenum is a major source of influx for the apartment, it would be expected that SF_6 would travel from the plenum into the bathroom, into the living room, and finally into the outside corridor.

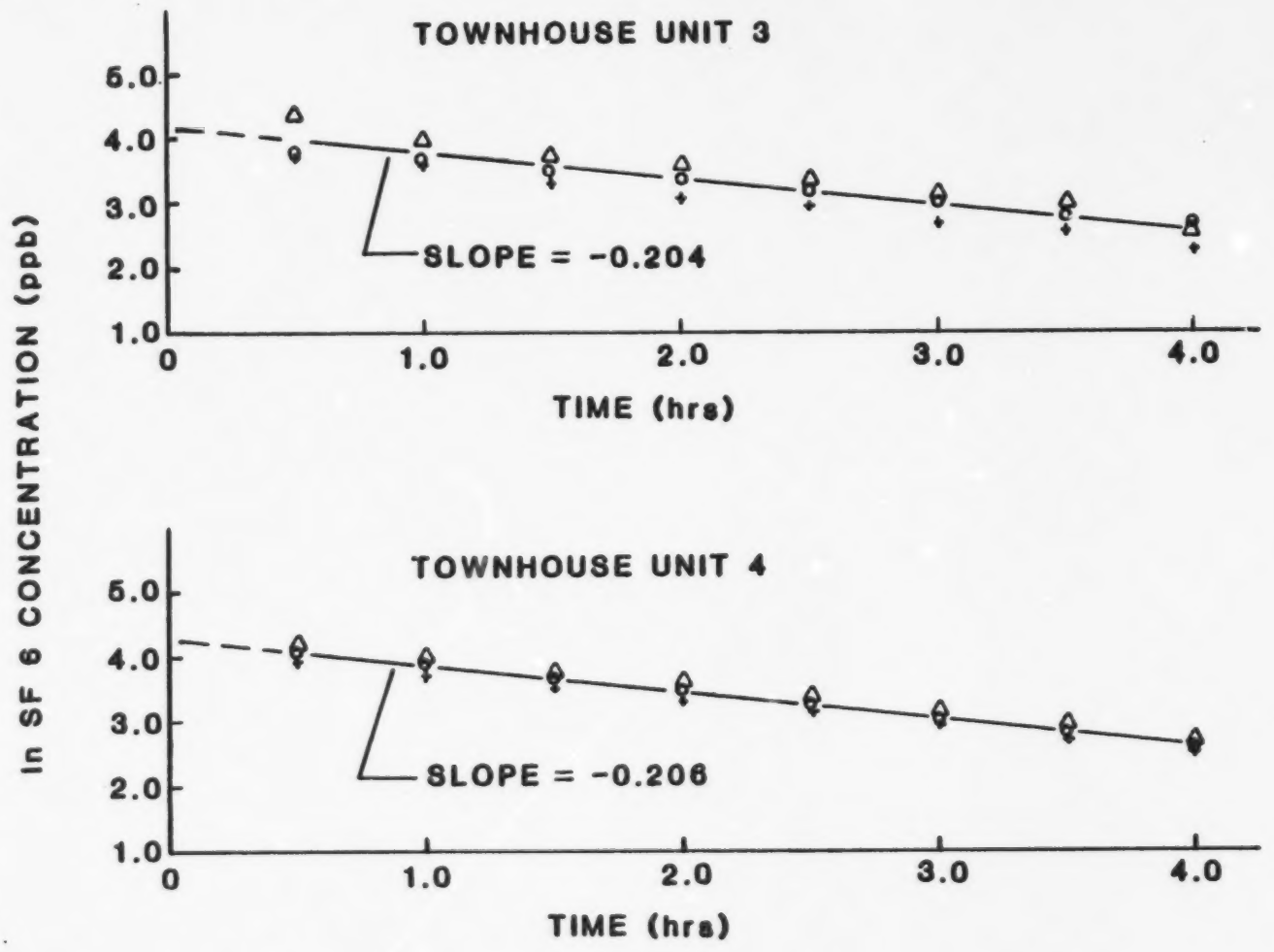
The data confirms this conclusion. The initial bathroom level is higher and reaches a peak, then begins to decay sooner than the levels in the living room. This time lag would be reversed or be less constant if there were another route of air entry from the units below.

An air change rate of 0.63 air changes per hour was established for apartment 3 on 10 February 1982. This is a fairly high rate compared to the two townhouses below. A significant flow of air is exiting under the door (confirmed by a smoke pencil), which is not weatherproofed, as in the townhouses below.

Stale air within the apartment was noted on both days of testing. This would be inconsistent with the high air change rate unless a significant portion of the make-up air is being introduced from the townhouses below. What appears to be happening is that the lower townhouse units are fairly tight, however, between these two units, a total volume of 4,000 ft^3 of air per hour is exiting, while the apartment above is expelling approximately 2,520 ft^3 per hour.

While it cannot be suggested that the total make-up air in the apartment is coming from the townhouses below, for the reasons stated above, it appears that a significant portion is. It is impossible to quantify the volume of air moving into the upper apartment through the pipe plenum unless a comparative air change is performed with the pipe plenum open and closed.

It would appear, therefore, that although the air change rate for the apartment is significantly higher than the lower townhouse units, warm moist air entering from below and exiting from the apartment is contributing to the humidity problems being experienced in the apartment units.



APPENDIX 6

SF 6 TESTING 1641 DAVENPORT ROAD

FIG. 1

APPENDIX 6

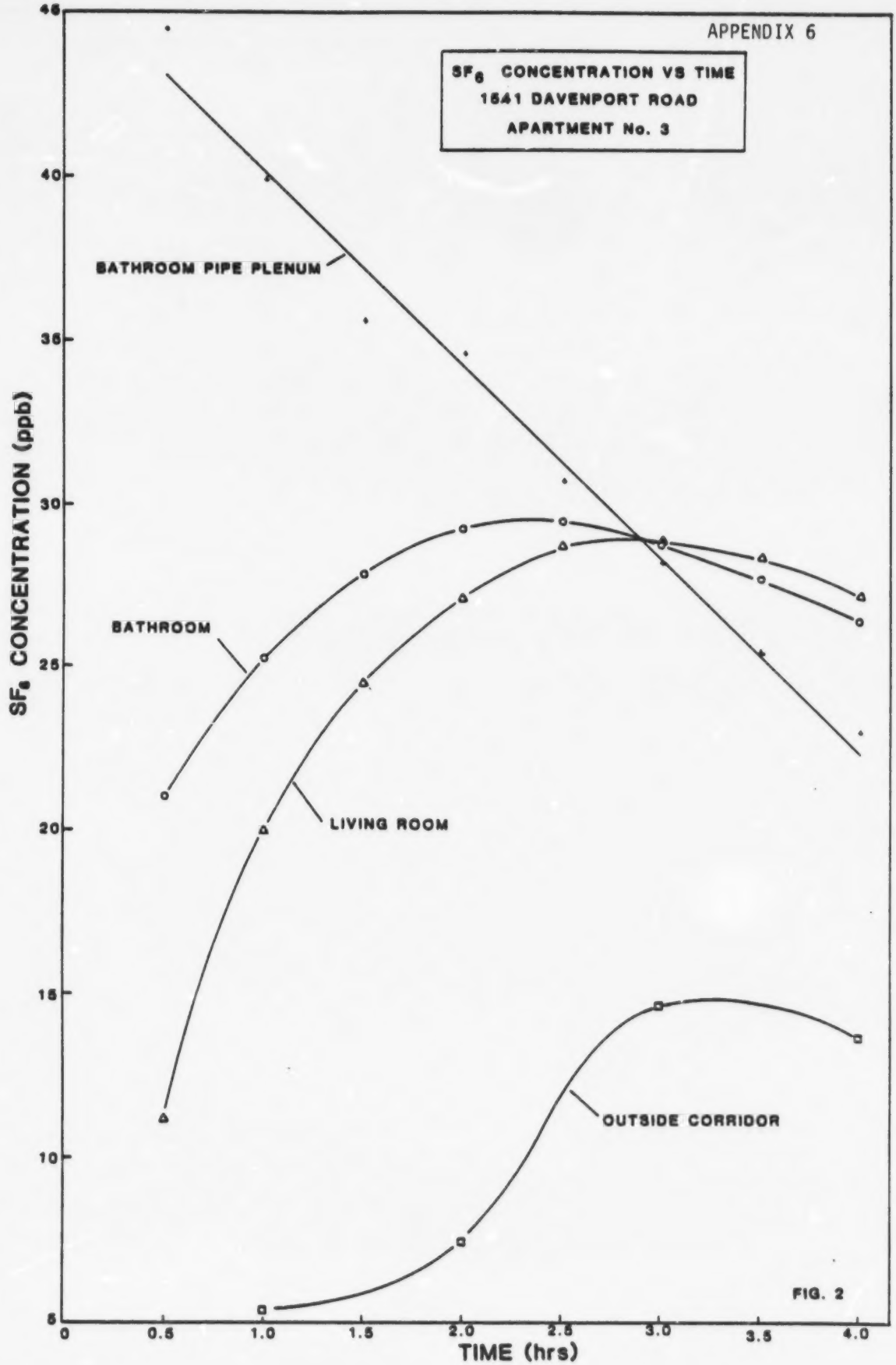
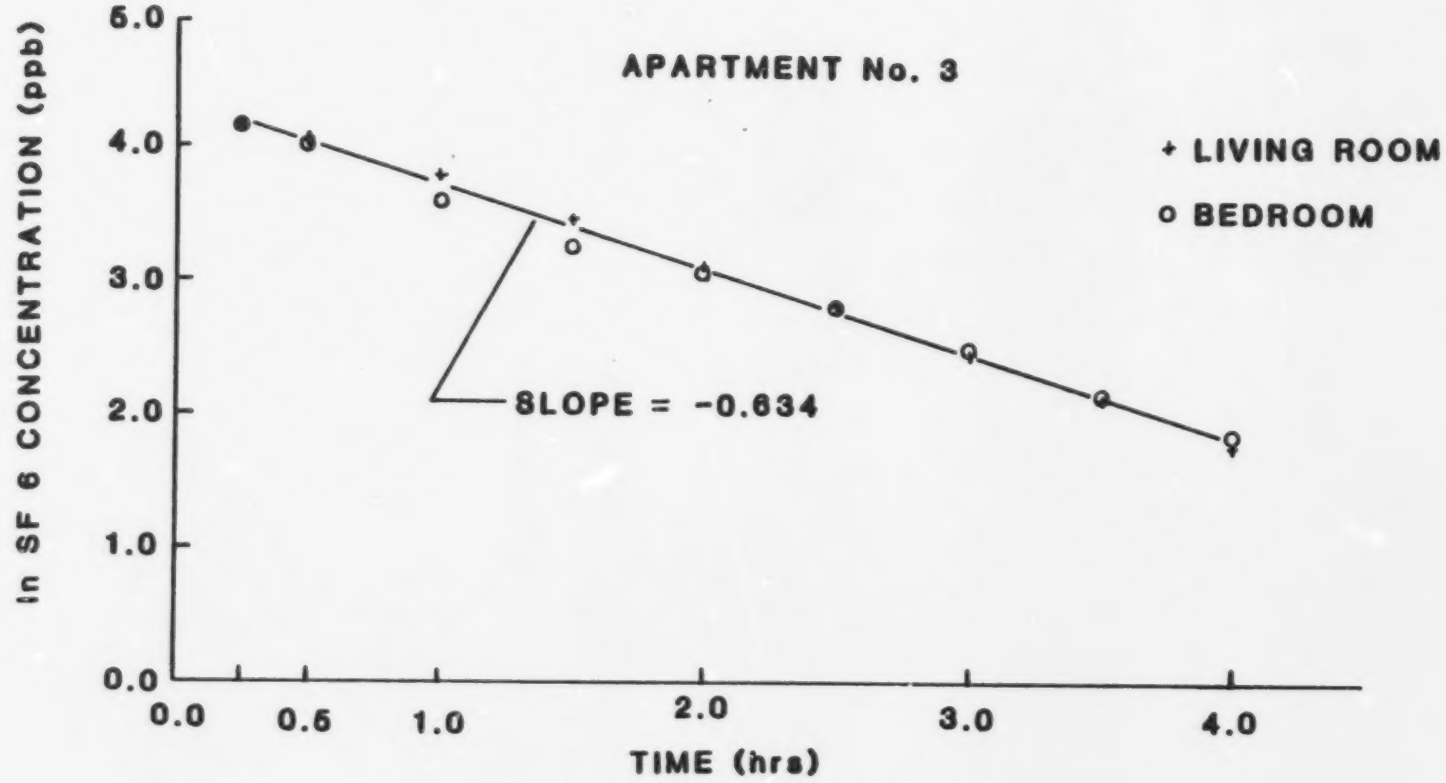


FIG. 2



APPENDIX 6

SF 6 TESTING 1541 DAVENPORT ROAD

FIG. 3

1541 Davenport Road - SF_6 Testing

Meteorological Data - 5 February 1982

(A.E.S. Toronto)

Time - 12 Noon

Outside Temperature - $-12^{\circ}C$

Barometric Pressure - 103.2 kPa

Wind - NE at 9 K.P.H.

Meteorological Data - 10 February 1982

Time - 12 Noon

Outside Temperature - $-15^{\circ}C$

Barometric Pressure - 102.3 kPa (72%)

Wind - WSW at 17 K.P.H.

1) Energy Costs of Slab Heating:

Theoretical calculations indicate that consumed electrial energy will be approximately $12.00 per year* for each slab location to which controlled heating is applied. These calculations however contain a large amount of uncertainty and an accurate projection of cost can only be obtained by measurement of consumption during a typical heating season.

The slab heating method suggested uses thermofilm lo-density heating strip adhered to the underside of the projected slab and controlled by an adjustable set-point controller the sensor for which is imbedded in the slab.

2) Capital Costs of Slab Heating:

Based on the budget prices received to date, installation of slab heating hardware, controls and necessary patching will cost about $500.00 per point.

3) Capital Costs of Insulation:

Exterior-applied insulation was considered for the locations of concern, that is, over the entrances under closets in Block 1, (III-c) and over the entrances adjacent to exterior walls in Block 2, (II-c). Rigid insulation with aluminum cladding was assumed and application was assumed to cover the exposed shear-wall, soffit and partial slab edge. In the Block 2 case, insulation and cladding was presumed to extend to cover 3' of the exposed end wall, extending approximately 20' vertically to cover this end wall section in a uniform fashion.

Cost per location were estimated to be $500.00 and $1,300.00 per location for Blocks 1 and 2 respectively. It should be noted that the effectiveness of this measure is not certain, particularly in the case of Block 2, and that the locations considered in Block 1 may not require remedy dependent on the results of this winter's trials.

4) Energy Savings Due to Insulation:

Theoretical calculation yields an approximate annual savings of $20.00 in the first year, over and above the present cost of heating, that is; when compared to slab heating, the insulating remedy has a total annual benefit of $32.00 in energy terms. It should, however be noted that the level of uncertainty contained in these calculations is very high and that accurate projections of benefit can only be obtained from the results of field trials.

5) Summary:

Slab Heating:	-Captial Cost/Location	$500.00
	-Energy Cost/Location	$12.00/year*
Insulation:	-Capital Cost/Location (Block 1)	$500.00
	-Captial Cost/Location (Block 2)	$1,300.00
	-Energy Savings/Location	$20.00/year
	-Energy Benefit/Location when compared to Slab Heat	$32.00/year

*Note: Actual monitored cost is +/- $6.00/year.

APPENDIX 8

MOISTURE INDUCED PROBLEMS IN NHA HOUSING

PART 2 OF A 3 PART SERIES

LITERATURE REVIEW AND RESEARCH

Prepared For:
The Research Division
Policy Development and Research Sector
of
Canada Mortgage and Housing Corporation
by
MARSHALL MACKLIN MONAGHAN LIMITED
Consulting Engineers, Surveyors, Planners
Toronto

Principal Consultant: J. Timusk, Ph.D
University of Toronto

CMHC Project Manager: Alvin J. Houston

3.0 MOULD AND MILDEW ON ROOM-SIDE ENCLOSURE SURFACES

3.1 General

This chapter deals with the part of the building enclosure located on the room-side of the vapour retarder. The influence of the part of the enclosure on the outside of the vapour retarder will only be considered as far as it affects room-side surface temperature. Since the vapour retarder forms a physical barrier between the inside and the outside, moisture damage to the room-side does not necessarily indicate that the wall itself is in distress. Conversely, a wall where structural damage has occurred as a result of moisture need not experience visible room-side problems.

"The occurrence of visible condensation on the room-side surfaces of windows, walls, floors and ceilings depends upon the combination of the relative humidity and the extent of cooling produced at the surface in question".[4)]

Room-side surface temperature is, therefore, of interest in that it affects comfort as well as dust marking or "thermal dusting" and mould and mildew formation on wall surfaces.

"Thermal dusting" is apparently caused by relatively small variations in surface temperature at thermal bridge locatons or caused convection within wall cavities.[5)] It has been suggested that a temperature difference of from 3 to 5°F (1.5 to 3.0°C) on the wall surface may produce noticeable dust patterns.[6)]

Mould and mildew formation on walls, caused by the creation of an environment favourable for its growth, is more serious since, in addition to aesthetic considerations, there is also concern about psychological and health aspects.[7)]

When dealing with the growth or survival of mould and mildew forming organisms, factors such as surface temperature, availability of moisture and the chemical nature of the surface are all important factors.

3.2 Reasons for Mould and Mildew Formation

It is not known whether actual condensation, or merely a more or less sustained high relative humidity in the air film next to the exterior wall or attic ceiling, is a prerequisite for mould and mildew growth. What is known is that the combination of high room-side relative humidity and lower envelope surface temperature are both critical factors. Envelope surface temperature depends on factors such as indoor and outdoor temperature, thermal resistance of the enclosure, air leakage through the envelope, convection within the wall system, air currents acting on the inside and outside envelope surfaces, etc. Room-side relative humidity depends, to a large degree, on occupant lifestyle, moisture released by the building itself and air change rate.

It is, therefore, necessary to establish the factor most effective in controlling condensation, be it a change in envelope surface temperature or a change in indoor relative humidity. Curves for different outdoor temperatures, relating wall surface temperature to the thermal resistance of the wall were plotted and are shown in Figure 3.1. In order to simplify the curves, indoor temperature (taken here to be 20°C) and the surface film resistance (taken to be 0.011 $m^2.°/W$) have been assumed fixed.* For analysis purposes, similar sets of curves were also plotted for indoor temperatures of 10°C and 23°C, representing closet and ground floor temperatures respectively. These curves were used in analysis, but are not presented here.

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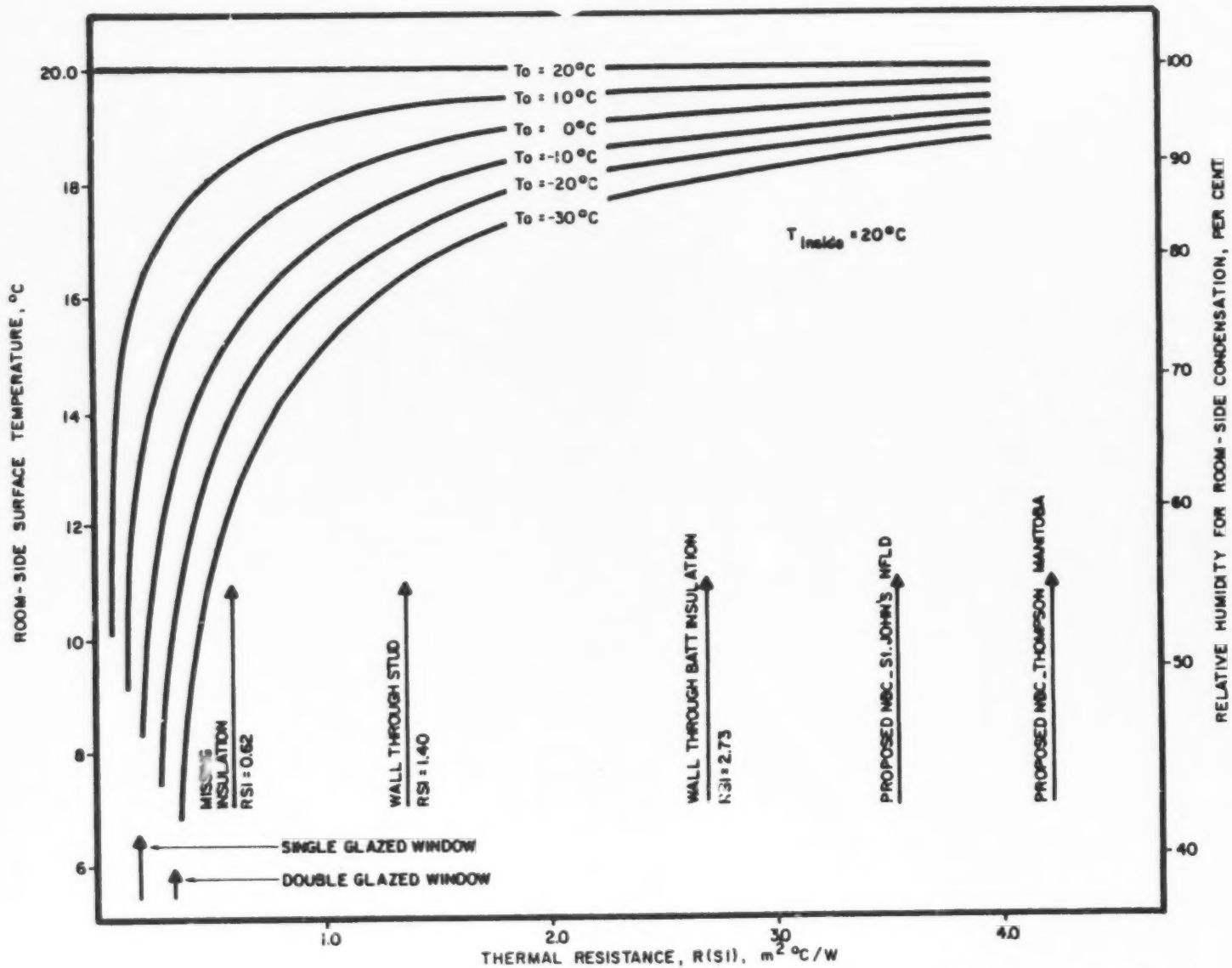
* The resistance to heat flow is, therefore, measured in watts per square metre per degree Celsius temperature difference across the material thickness.



A PLOT OF THERMAL RESISTANCE AGAINST ROOM-SIDE SURFACE TEMPERATURE OR ROOM-SIDE RELATIVE HUMIDITY LEADING TO CONDENSATION ON WALLS

FIG. 3.1

To determine the wall thermal resistance at the point of condensation, for a predetermined room relative humidity and outdoor temperature, a horizontal line from the relative humidity value on the right vertical axis is drawn to intersect the curve for the selected outdoor temperature. The point of intersection will then determine the desired thermal resistance value. For reference purposes, thermal resistance values for windows and various parts of "standard" 2 in. x 4 in. (38 mm x 89 mm) stud walls, have been included.

The wall curves in Figure 3.1 show that, the likelihood of condensation on a given surface also increases as the thermal resistance of the wall and outdoor temperature decrease and the indoor relative humidity increases. These curves also show that, in the low R-value range, a small increase in thermal resistance will have a large effect on reducing potential condensation. At the higher R-values the same incremental increase in R-value will have only a very small effect on condensation potential. In this case, the thermal resistance of the air film adjacent to the inside wall surface decreases as an important component of the total resistance of the wall system.

At high relative humidity levels (80%), there is complete agreement between field observations and the theoretical discussion summarized in Figure 3.1 concerning the onset of condensation. Although such high levels of relative humidity are virtually impossible to sustain in open spaces during cold weather, extremely high RH levels are possible in areas where localized cooling takes place. These locations are found in closets, under carpets, behind curtains, clothing and wall hangings against exterior walls. At these high relative humidity levels, increases to the thermal resistance of the wall will not prevent condensation. Localized cooling due to unintentional insulation on the warm side of the wall surface must, therefore, be avoided.

However, at the 50 - 70% RH levels, a major discrepancy between field observation and the theory as summarized in Figure 3.1 is noted. For example, condensation on a wall surface with missing

insulation is not shown to start before the outdoor temperature falls below -30°C and the indoor relative humidity exceeds 65 percent. Similarly, mould and mildew should not take place at a stud location until the indoor relative humidity exceeds about 75 percent. Such condensation was, however, common in problem buildings (at higher outdoor temperatures and lower indoor relative humidities). Field observations, therfore, suggest that, in certain spots in the wall, air movement has resulted in inside surface temperatures lower than would normally be expected.

Laboratory measurements have demonstrated that, three-dimensional heat flow and wall cavity convection resulting from careless installation of insulation, can lead to substantially lower surface temperatures than those predicted by the theoretical parallel heat path modelling, used to derive Figure 3.1.[6, 8, 9] The observed discrepancies are, however, still too large. It is suspected that infiltrating cold air or cold air taking a "short cut" through the wall construction and although not penetrating the air/vapour retarder, is by-passing the siding sheathing and insulation complex as well as the studs. Insofar as the room side surface temperatures are concerned, at localized spaces the envelope is only composed of the air/vapour barrier and dry-wall.

Poor detailing and workmanship found during the field observations, strongly support suspected cooling of interior surfaces by forced convection within wall systems.

3.3 Effect of Climate on Mould and Mildew Growth

Mould and mildew was found in all areas which experience extreme climate. The major contributing factors are:*

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* Details supporting these comments can be found in: "Moisture Induced Problems in NHA Housing. Analysis of Field Survey Results and Projection of Future Problems" - Part 1 of Contract 176-4-25 by Marshall Macklin Monaghan Limited.

- Low outdoor temperature, such as in Thompson, Manitoba;

- High indoor relative humidity, which in turn arises from the combination of high outdoor vapour pressures and high indoor moisture content (Newfoundland, the Maritimes and B.C. coastal regions are, therefore, affected);

- Exposure to winds. This study has shown a strong correlation between first floor mildew problems and exposure to strong winds. Here wind and stack action combine to promote air infiltration and thereby cooling of interior surfaces.

3.4 Wall Conditions Favourable for Mould and Mildew Growth Caused by Low Indoor Temperatures

The vapour pressure within a dwelling depends on the outside relative humidity, the rate of moisture gain within the enclosure and the number of air changes experienced. With reasonable internal ventilation, similar vapour pressures can be expected within the various parts of a dwelling. This does not apply to temperature and relative humidities, as these can vary with time, from room to room, and with variations in heat input and heat loss.

The moisture content of the air in a house will be fairly constant at any one point in time. In the bedrooms, where temperatures are usually lower, the RH will be higher than the RH on a warmer first floor.

If, for example, the temperature on the lower floor of a two storey house is 23°C and the relative humidity is 50%, the upstairs, with an 18°C temperature, would be expected to have a relative humidity of just below 70 percent. A greater incidence of mildew formation on the second floor was indeed observed in the survey.*

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* Details supporting these comments can be found in: "Moisture Induced Problems in NHA Housing. Analysis of Field Survey Results and Projection of Future Problems" - by Marshall Macklin Monaghan for CMHC 176-4-25. (Part 1)

Relative humidities would be even higher inside a closet adjacent to an exterior wall. The worst case is the cantilevered closet, where heat gain is only experienced through the closet door and heat is lost to the outside through the three exterior closet walls,* the floor and the ceiling. If indoor air at 23°C and a relative humidity of 50 percent is cooled to 12°C in a closet, the relative humidity in the closet would reach 100 percent.

Conditions in a closet are even worse if clothing resting against the closet wall and items stored on the closet floor interfere with air circulation and act as additional insulation. This will further lower the inside wall temperature. Freezing of clothing to closet and hallway walls, and the formation of mildew behind such clothing, was reported in Thompson, Manitoba. In Newfoundland, mould formation in clothing has been reported in cantilevered closets.

3.5 Recommendations for Existing Problems

As seen in Figure 3.1, only a very small amount of insulation is needed to increase the wall temperature to a point where condensation, for reasonable to high relative humidities, should not occur.** It is therefore important to impede the movement of cold outside air in the wall system. As a retrofit action, this will, however, require the removal of the siding to ensure the installation of a continuous exterior air barrier.

Probably the simplest and least costly measure would involve placing a relatively thin layer of insulation over the room side face of the wall at the point where condensation is occurring. In most cases, only an area 200 mm beyond a particular corner would need to be covered. While this will change the appearance of the interior, it can be considered as a cornice for the wall ceiling junction, and may even enhance the appearance of the wall.

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* These walls are non-structural.

** It takes only a small increase in R value to "move" along the curve in Figure 3.1 from the vertical to the horizontal portion.

The insulating corner pieces could be prefinished with a fire protective layer and fastened with an adhesive. This adhesive would also provide the essential airtight seal between the wall and the insulation.

In less severe cases, the painting of affected surfaces with a non-absorbent oil paint may be effective. If water is prevented from being absorbed by the dry-wall, a moisture reservoir which would otherwise supply moisture during dry conditions, would be eliminated.

Where siding has to be replaced, it would be preferable to add insulating sheathing in conjunction with a vapour permeable but airtight air barrier, such as a spunbonded olefin film* or similar material. This approach will be dealt with in greater detail in Section 6. In most cases**, the insulated sheathing could be applied directly over the existing sheathing. However, care will need to be taken with the attachment detailing for the siding.

Because of high relative humidity conditions, closets with walls to the exterior may not respond to increasing the insulation on walls. It is, therefore, proposed that an attempt be made to increase closet ventilation. Although not yet tested in practice, this could be accomplished by creating openings on the top and the bottom of the closet door. Openings would provide a means for entry and exit of room air. A sheet of rigid board, such as masonite, could then be placed on furring strips against the exterior wall and the floor, creating a vented wall cavity, open to the warm room air. Continuous circulation through the cavity would be set up, bringing warm room air into the closet. The rigid board would perform yet another function, as it would prevent clothing and items stored against the closet wall and on the floor, from coming in contact with the cold surfaces.

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* An airtight but vapour permeable film.

** Although this area is currently being researched, it is thought that under most climatic conditions this approach is acceptable even though plywood sheathing with an externally applied insulating sheathing can create an effective vapour barrier. In very cold climates, however, moisture accumulation within the wall cavity could become excessive.